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PROPANE POOL-FIRE TESTING OF HALF-SCALE ROAD CASK

Report No 90-202-K

D. Taralis / G. Morandin
Engineer / Technologist
Applied Mechanics Section
Mechanical Research Department

ABSTRACT

Propane pool-fire testing of the half-scale road cask has been carried out jointly by Ontario Hydro and the National Research Council (NRC) using the NRC fire test facilities. The cask model was instrumented with 37 thermocouples (T/C's). The fire test duration was calculated using temperature data obtained from 16 additional T/C's placed within the fire. Temperature measurements were made during and after the fire test until the cask model had cooled to ambient conditions. The maximum lid seal temperature (112 °C) was attained approximately 2.5 hours after the fire. Comparisons of propane with kerosene fire test results revealed lower propane flame temperatures. As a result, the test duration for the propane fire (14 minutes) had to run longer (to meet scaling law temperature requirements) than the kerosene fire (11 minutes). However, the temperature profiles for both tests were similar with maximum model temperatures being approximately the same.

job	file	date	report
21-134-401	825.122	December 7, 1990	90-202-K

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EXECUTIVE SUMMARY

PROPANE POOL-FIRE TESTING OF HALF-SCALE ROAD CASK

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This report presents the results of a propane fire test on a half-scale road cask carried out by Ontario Hydro and the National Research Council at the NRC fire test facilities. The purpose was to determine whether propane fire testing could be used as an alternative to kerosene fires. The results of these tests include :

1. Flame temperatures at 16 locations
2. Cask model temperatures at 37 locations
3. Comparisons of propane-versus-kerosene fire test results

The maximum outer surface temperature occuring at the end of the fire was 675 °C while the inner lid seal reached a maximum temperature of 112 °C during the cooling period. Comparison of measurements for the propane fire with those from the kerosene fire revealed lower propane flame temperatures. Although the duration of the propane test had to run longer to meet scaling law temperature requirements, the overall cask temperatures for both tests were similar.

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TABLE OF CONTENTS

1.0 INTRODUCTION	1
2.0 FIRE TEST FACILITY	2
3.0 TEST APPARATUS	2
4.0 INSTRUMENTATION	2
5.0 DATA ACQUISITION SYSTEM	2
6.0 FIRE TEST AND TEMPERATURE RESULTS	3
7.0 COMPARISON OF PROPANE AND KEROSENE RESULTS	5
8.0 CONCLUSIONS AND RECOMMENDATIONS	5
ACKNOWLEDGEMENTS	7
REFERENCES	7a
FIGURES	8 - 39
TABLES	40 - 41
DISTRIBUTION	-Last Page

LIST OF FIGURES

1. Half-Scale Road Cask
2. Impact Limiter
3. T/C Locations and Numbering Scheme
4. Data Acquisition System
5. Preheating of Half-Scale Road Cask
6. Half-Scale Road Cask Before Fire Test
7. Water-Cooled Heat Flux Meter
8. Initial Stages of Fire Development
9. Intermediate Stages of Fire Development
10. Final Stages of Fire Development
11. Half-Scale Road Cask After Fire Test
12. Flame Temperatures at Four Positions
13. Flame Temperatures at Four Levels
14. Average Instantaneous Flame Temperatures
15. Average Instantaneous and Time Average Flame Temperatures Based on 16 Flame T/Cs
16. Heat Flux Measurements
17. Outer Wall Temperatures
18. Outer Sheath Impact Limiter Temperature
19. Inner Lid Seal Temperatures
20. Inner Wall and Cavity Temperatures
21. Fire Hall Temperature
22. Comparison of Averages of Flame Temperatures
23. Comparison of Impact Limiter Temperatures
24. Comparison of Outer Top Surface Temperatures

25. Comparison of Outer Middle Surface Temperatures (Centre)
26. Comparison of Outer Middle Surface Temperatures (Corners)
27. Comparison of Outer Bottom Surface Temperatures
28. Comparison of Inner Top Surface Temperatures
29. Comparison of Inner Middle Surface Temperatures
30. Comparison of Inner Bottom Surface Temperatures
31. Comparison of Inner Lid Seal Temperatures
32. Comparison of Cavity Temperature

LIST OF TABLES

1. Summary of Propane Fire Test Results
2. Summary of Propane vs Kerosene Fire Test Results

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To

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PROPANE POOL-FIRE TESTING OF HALF-SCALE ROAD CASK

1.0 INTRODUCTION

The present study deals with the propane fire testing of a half-scale road cask in connection with the transportation of 10 year cooled fuel (Reference Case). It involves carrying out one fire test within the Atomic Energy Control Board (AECB) requirements (0.5 hour at 800 °C flame temperature on full scale cask). For the half-scale model the fire test duration was determined according to scaling laws described in reference /1/. The main objectives of this study were as follows:

i) To determine the temperature range occuring at the seal locations,

ii) To obtain flame and model temperatures for comparison with previous kerosene fire test results, and

iii) To determine if any significant advantages (such as very low pollution levels) exist in using propane instead of kerosene.

On the basis of the needs of this study it was determined that the Institute for Fire Research in Construction of the National Research Council (NRC) of Canada was suitable for conducting the test.

This report presents the propane fire test results as well as the comparisons of propane with previous kerosene fire test results and states the main conclusions and recommendations of this study.

2.0 FIRE TEST FACILITY

The propane fire testing of the half-scale road cask took place at the NRC fire hall which is situated near Almonte, Ontario. More details on the fire test facility can be found in reference /1/.

3.0 TEST APPARATUS

The experimental set-up for conducting the propane fire test consisted of the following components:

a) Half-scale road cask (see Figure 1)

b) Impact limiter (see Figure 2)

c) Cask model support

d) Propane burner and gas supply

References /1,2/ describe the test apparatus in sufficient detail and it will, therefore, not be repeated here.

4.0 INSTRUMENTATION

In total, 54 type K thermocouples (1/16" Inconel sheath) were used to make the temperature measurements at the desired locations (see Figure 3). In addition one heat flux meter /2/ (water-cooled) was used to measure the total heat flux (convective and radiative) seen by one of the cask vertical surfaces.

5.0 DATA ACQUISITION SYSTEM

The data acquisition system (see reference /3/) consisted of:

a) Orion data logger

b) Compaq computer

c) Printer

This system is shown in Figure 4. During the fire test a series of computations were performed to determine the following:

a) Time average of the 16 flame temperatures

b) Required test duration based on scaling laws

c) Elapsed time from the start of the test

d) Time remaining in test

The above quantities were computed from the equations given in reference/1/.

6.0 FIRE TEST AND TEMPERATURE RESULTS

This section briefly describes the fire test conducted at the NRC fire test facility (see also reference /4/) and presents the results of the temperature measurements.

The half-scale cask model with the impact limiter over the lid was placed on the support. To simulate the initial conditions of the actual road cask with insolation (solar heating) and spent-fuel, the model was preheated with controlable electric resistant heaters (see Figure 5) to an average temperature of approximately 60 °C (with +/- 10 °C variation across the wall).

Figure 6 shows the half-scale road cask before ignition of the propane burner. The total heat flux to one of the vertical cask surfaces was measured using the flux meter shown in Figure 7. When the data acquisition system and the video equipment were ready, the signal for starting the fire was given. The development of the fire is shown in Figures 8,9 and 10. A fully engulfing fire was established approximately 35 seconds after ignition. Figure 11 shows the cask immediately after the fire.

Figure 12 shows the instantaneous flame temperatures at four positions (locations) around the cask (each position has four T/Cs in the vertical direction). This figure reveals that the flame temperatures at position 1 were lower than the other three positions. As was observed during the test this side of the model was not continuously engulfed by the flame. The same flame temperatures are shown in Figure 13 for four different elevations (levels). As can be seen from this figure two of the flame temperatures (T/C'S 4 and 8) at level 4 are lower than all the temperatures at the other levels since this side of the cask model was not fully engulfed by the flame. Figure 14 shows the calculated instantaneous flame temperatures at the four locations. Figure 15 shows the average instantaneous and the time average of the flame temperature based on the 16 flame T/C

readings. The test lasted approximately 14 minutes (corresponds to 30 minute fire on full-scale cask). To meet scaling requirements the test duration was continuously recalculated throughout the test at 10 second intervals using the time average of the flame temperature as it was relatively steady (820 °C during the test period).

Figure 16 shows the total heat flux (convective and radiative) measured during the fire test. As can be seen from this figure the heat flux fluctuates considerably about a mean value of 125 kW/m^2. This value compares well with that reported in reference /5/.

The temperature measurements made on the cask model are presented in Figures 17 through 20. The outer wall temperature of the cask model reached a maximum value of 675 °C at the end of the fire (see Figure 17). This occured at the bottom of the model. The outside surface of the impact limiter reached a temperature (see Figure 18) which was close to the time average of the flame temperature (780 °C) as expected since the stainless steel sheet encasing the redwood is very thin (3 mm) and heats up readily.

The maximum lid seal temperature measured (see Figure 19) was 112 °C which not surprisingly corresponded to the side of the container where the hottest flame temperatures were recorded. This value was attained approximately 2.5 hours after the fire which is the result of the temperature wave propagating into the cask wall. In the absence of the impact limiter (which behaves as thermal insulator) the seal temperatures would have been even higher. Figure 20 shows the inner wall temperatures and the air temperature at the centre of the cavity. The maximum inner wall temperature reached was 220 °C while the cavity air temperature was 165 °C.

Figure 21 shows the fire hall temperature during the entire test measured approximately 6 meters away from the fire. As this figure illustrates, the hall temperature increased from about 9 °C to a maximum of 38 °C (at end of fire) and then decreased again down to ambient conditions (0 °C). These small changes in hall ambient temperature during the test did not affect the test results.

The major results of this test are summarized for convenience in Table 1.

7.0 COMPARISON OF PROPANE AND KEROSENE RESULTS

This section presents the comparison of the present (propane) temperature results with previous results /1/ obtained using kerosene fuel. The comparison of results are shown in Figures 22 through 32.

The average instantaneous and time average of the flame temperatures for propane and kerosene fires are shown in Figure 22. The propane flame temperature was lower by approximately 80 °C (820 °C vs 900 °C). This resulted in a longer test duration for the propane fire test (14 minutes vs 11 minutes). Figure 23 shows the comparison of the impact limiter temperatures. Again the impact limiter temperature is lower for the propane fire (780 °C vs 960 °C). The different initial temperatures of the impact limiter for the propane and kerosene fire tests has very little effect on the cask temperatures since the heat input to the cask through the impact limiter is negligible.

Figures 24 to 27 show the comparison of the cask outer surface temperatures. These figures indicate in general that during the fire the cask outer surface temperatures were somewhat higher for the propane test even though the flame temperatures were lower for the propane fire. Therefore, it appears that the total heat flux absorbed by the cask surface was higher. This could be, among other parameters (such as flame and surface emissivities and soot layer thickness) the result of higher heat transfer coefficient which depends mainly on gas velocities and gas thermal properties. However, the maximum outer surface temperatures attained were close for both fires (propane 675 °C vs kerosene 645 °C). The cask inner surface temperatures for both tests are shown in Figures 28,29 and 30. As these figures reveal, the inner surface temperatures are very close (except during the fire which is mainly due to the difference in the preheating temperatures of the model). The maximum inner lid seal temperature attained was slightly higher for the kerosene fire (114 °C vs 112 °C) as shown in Figure 31. The maximum cavity temperature for the propane fire was 165 °C while for the kerosene fire it was 160 °C (see Figure 32).

It appears from the above results that both fires have the same overall heat transfer characteristics in terms of inner and outer model surface temperatures. Table 2 summarizes the comparison of propane versus kerosene fire test results.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The main results of this experimental investigation are as follows:

a) The time average of the flame temperature during the fire test (820 °C) was, according to scaling laws, below the required temperature of 1005 °C. Because of this inadequate flame temperature, the half-scale fire test lasted approximately 14 minutes instead of 7.5 minutes as dictated by scaling laws (which corresponds to the half-hour regulatory test for the full scale cask).

b) Flame temperatures during the test fluctuated about a mean value of 820 °C (see Figure 14) with ± 160 °C fluctuations.

c) The maximum temperature of the cask outer surface was approximately 675 °C. This maximum temperature was attained at the end of the fire .

d) The outside sheath of the impact limiter reached a temperature (780 °C) which was very close to the flame temperature (820 °C). This is to be expected since the stainless steel sheath encasing the redwood is very thin and will heat up readily.

e) The lid seal temperatures reached a maximum value of 112 °C at approximately 2.5 hours after the fire. Due to the thermal insulating effects of the impact limiter, the lid seals temperatures remained relatively low.

f) Although the cask outer surface was covered with black soot the impact limiter was clean. This suggests that the higher the surface temperatures (i.e. above 600 °C) the less tendency for the soot particles to stick to the cask surfaces.

g) The effects of the soot layer on the outside surface of the cask could be beneficial in terms of reducing the heat conducted into the cask wall particularly for fires of longer duration.

h) Propane flame temperatures were lower than the corresponding kerosene flame temperatures. Although this led to a longer propane test duration , the overall cask temperature profiles were similar for both tests.

i) Both propane and kerosene fires have been found to produce significant quantities of black smoke (kerosene somewhat worse) without any major advantages of one over the other.

ACKNOWLEDGEMENTS

Ontario Hydro (Nuclear Engineering and Mechanical Research Departments) acknowledges the financial contribution and excellent cooperation of NRC in jointly carrying out this study.

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REFERENCES

1. Taralis,D and Morandin,G., "Fire Testing of Half-Scale Road Cask for 10 Year Cooled Irradiated Fuel, Ontario Hydro Research Division Report No 88-127-K, May 17,1988.

2. Crampton, G.P., "Fire Tests for a Half-Scale Road Cask Using a Large Propane Burner and a Propane Flare", National Research Council Report No. CR-5986.1, July, 1990.

3. Taralis,D and Morandin,G., "Wesleyville Pool-Fire Test Facility", Ontario Hydro Research Division Report No 90-85-K, April 15, 1990.

4. Taralis,D., "Propane Fire Testing of Half-Scale Road Cask - Test Preparation and Test Procedure", Memorandum to J.F. Tanaka, Dated October 17,1989.

5. Townsend, W., et al, "Comparison of Thermally Coated and Uninsulated Rail Tank Cars Filled with LPG Subjected to a Fire Environment", U.S. Army/Ballistic Research Laboratories, Report No. FRA-ORD 75-32, December,1974.

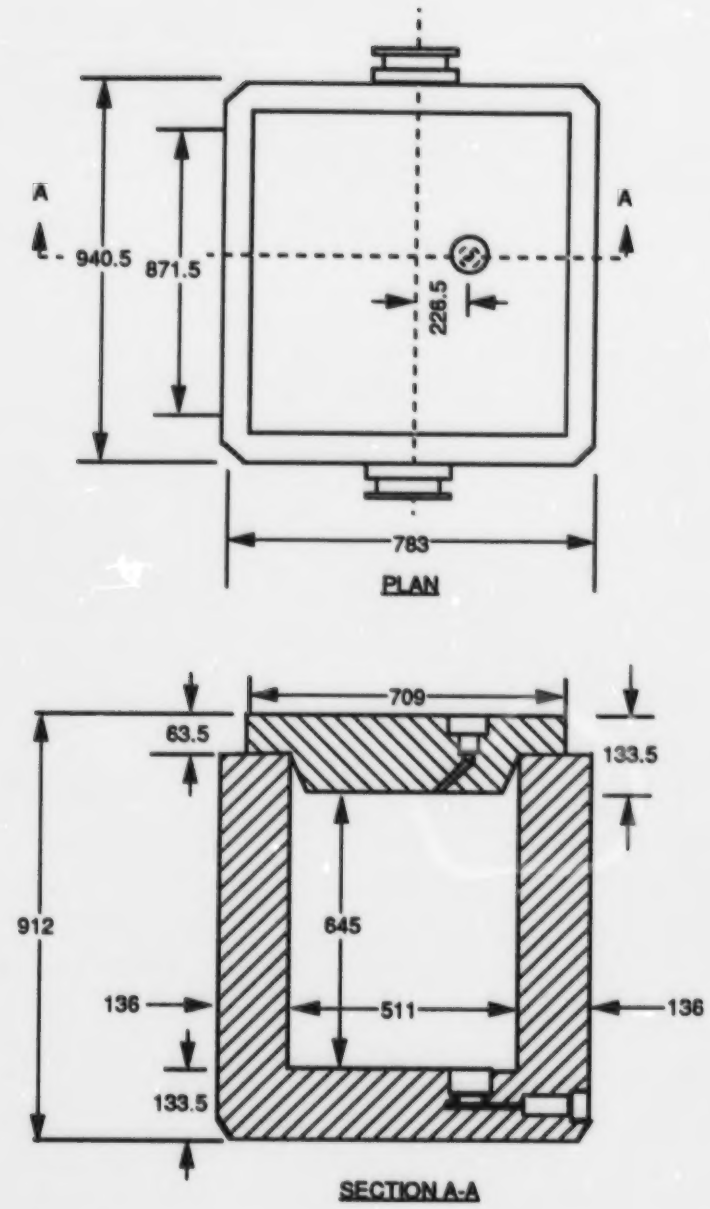
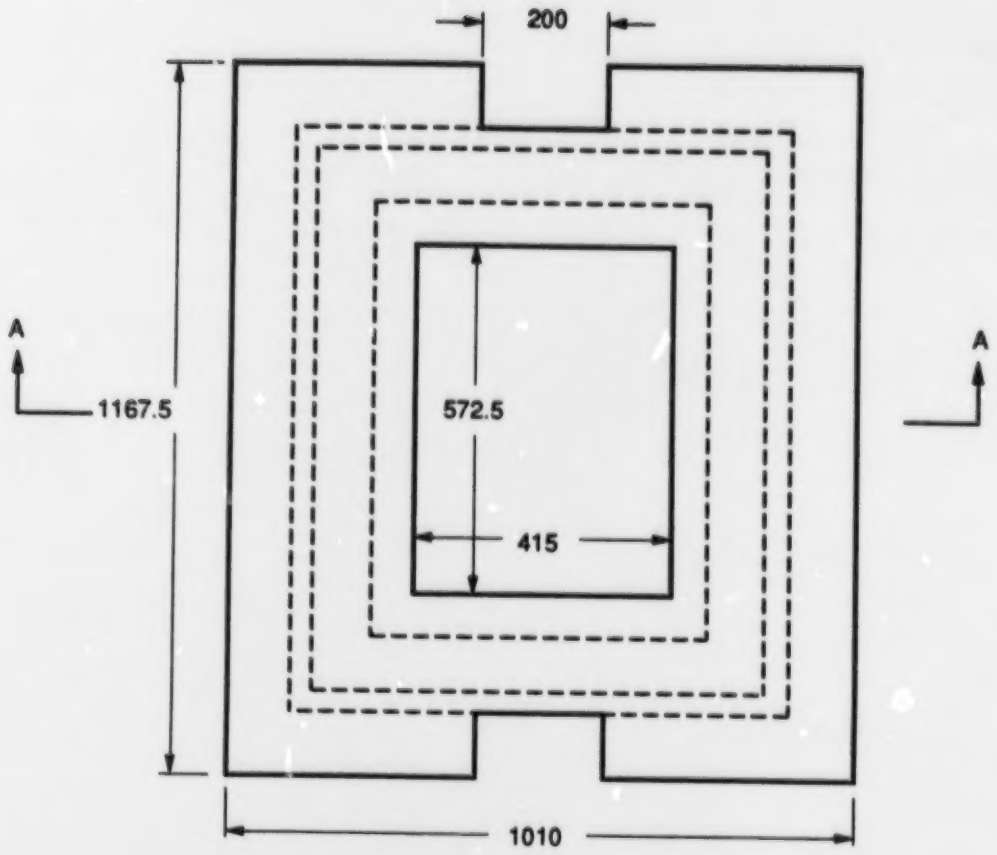
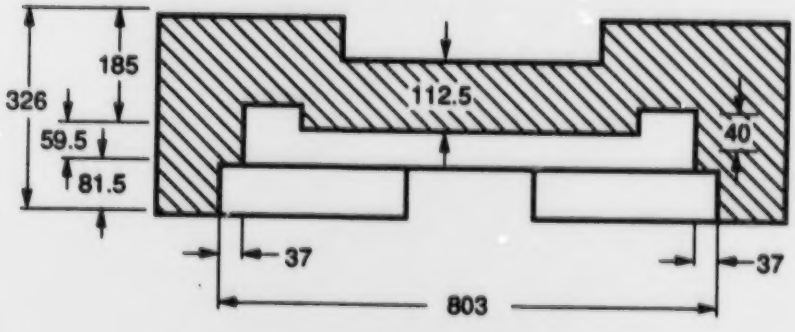


FIGURE 1

HALF-SCALE ROAD CASK



PLAN

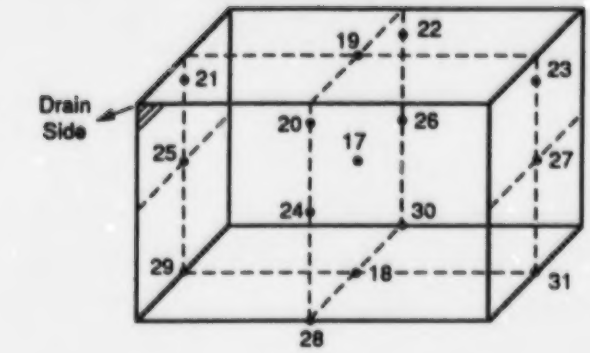


SECTION A-A

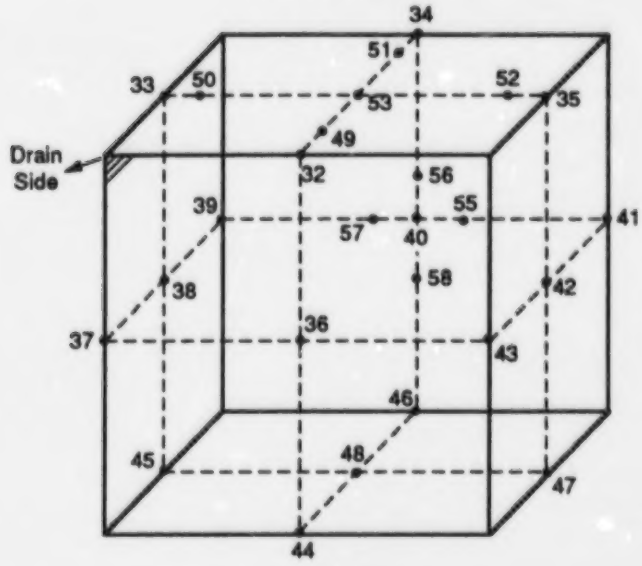
All Dimensions in mm

FIGURE 2

IMPACT LIMITER

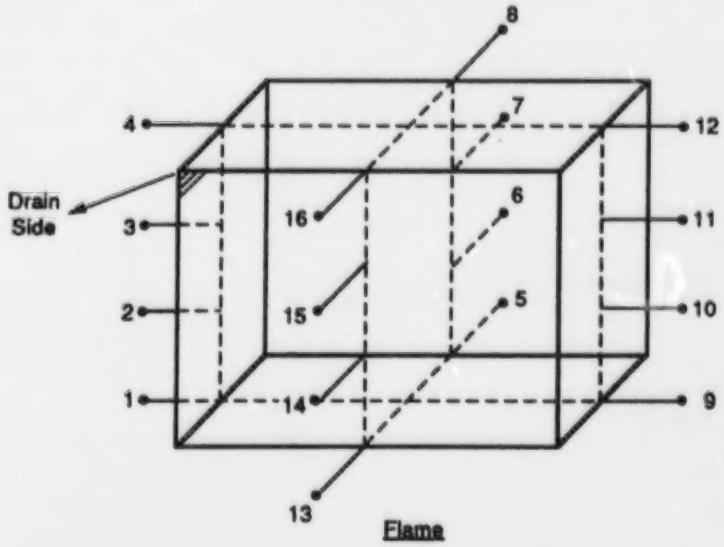


Inner Surface



Outer Surface

Ambient T/C 54
Lid Seals T/Cs 49, 50, 51, 52



Flame

FIGURE 3

THERMOCOUPLE LOCATIONS AND NUMBERING SCHEME

183749-S45-RD

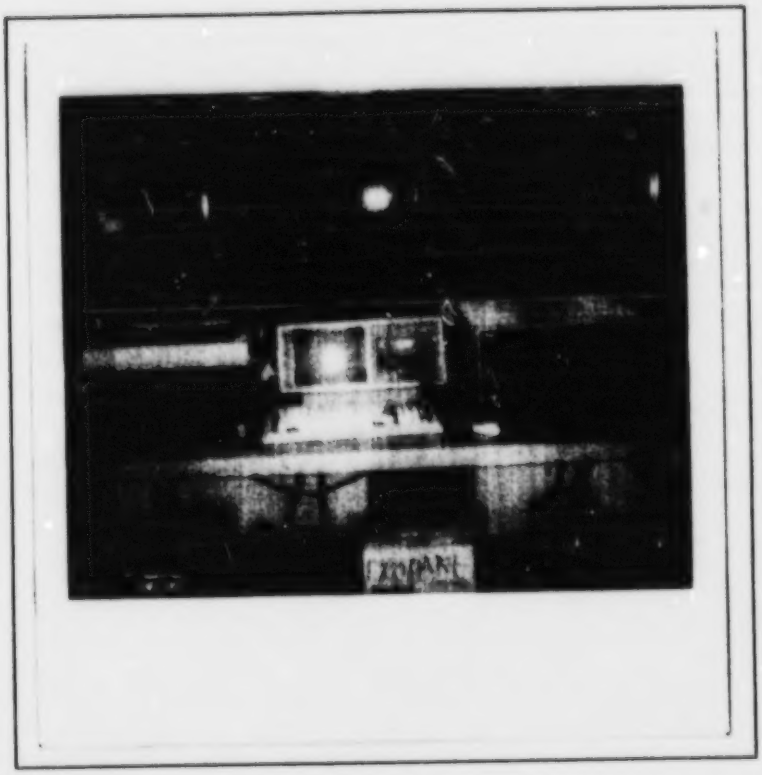


FIGURE 4

DATA ACQUISITION SYSTEM

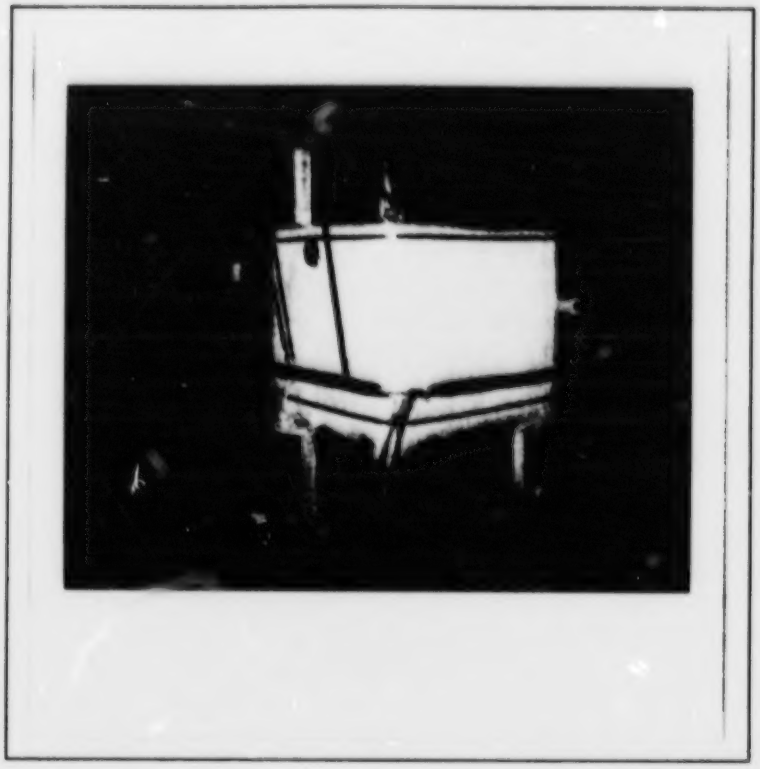


FIGURE 5

PREHEATING OF HALF-SCALE ROAD CASK

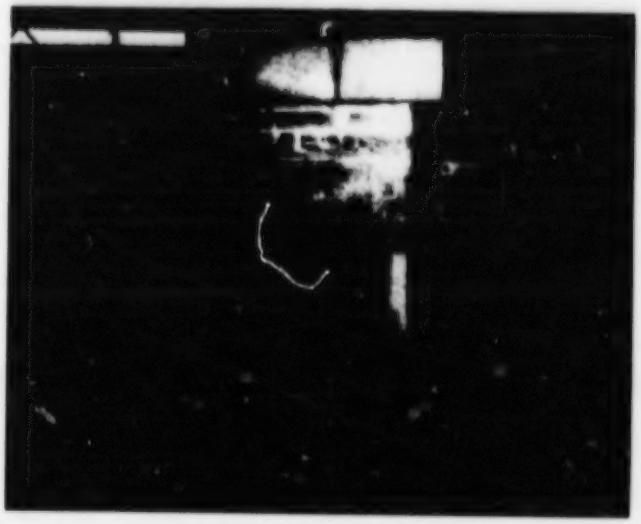


FIGURE 6

HALF-SCALE ROAD CASK BEFORE FIRE TEST

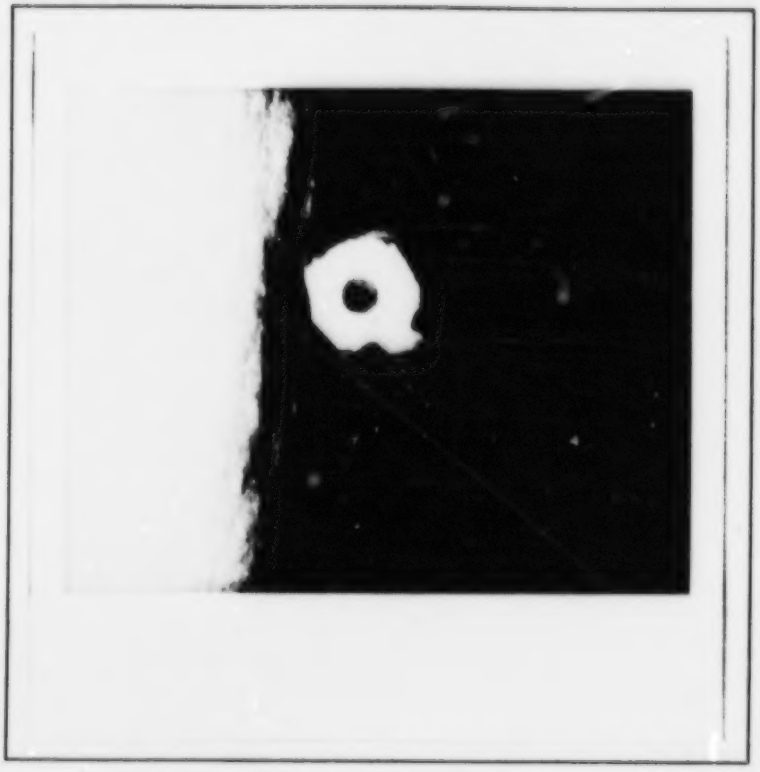


FIGURE 7

WATER-COOLED HEAT FLUX METER

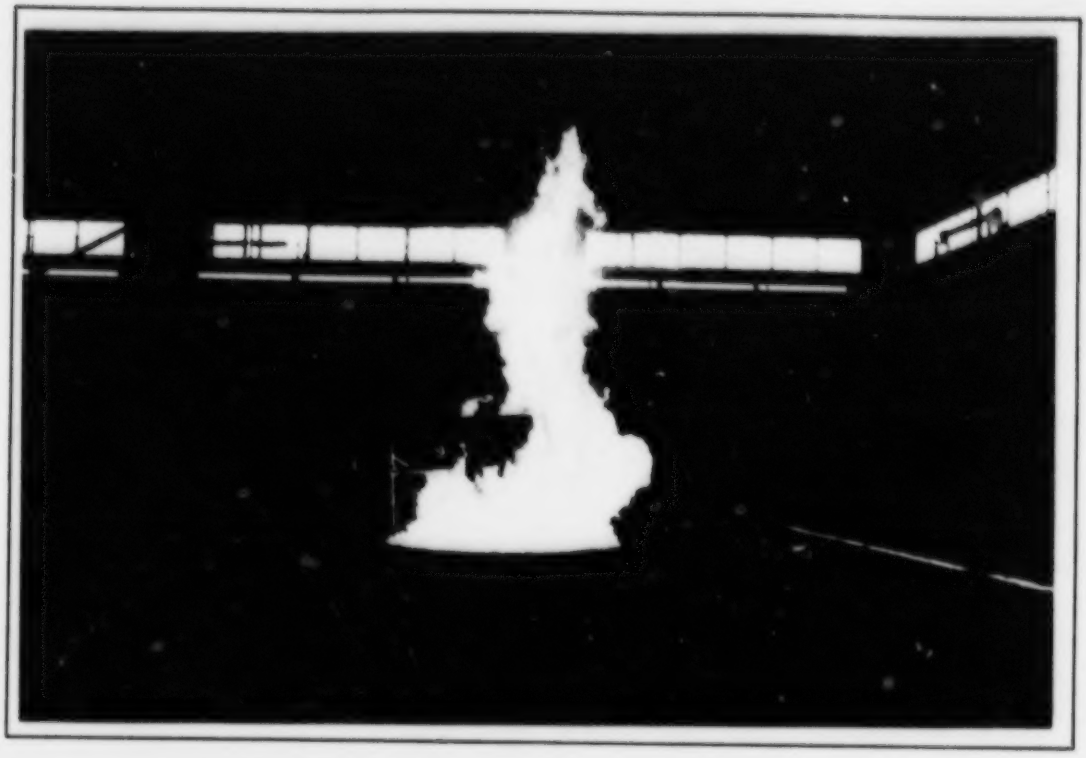


FIGURE 8

INITIAL STAGES OF FIRE DEVELOPMENT

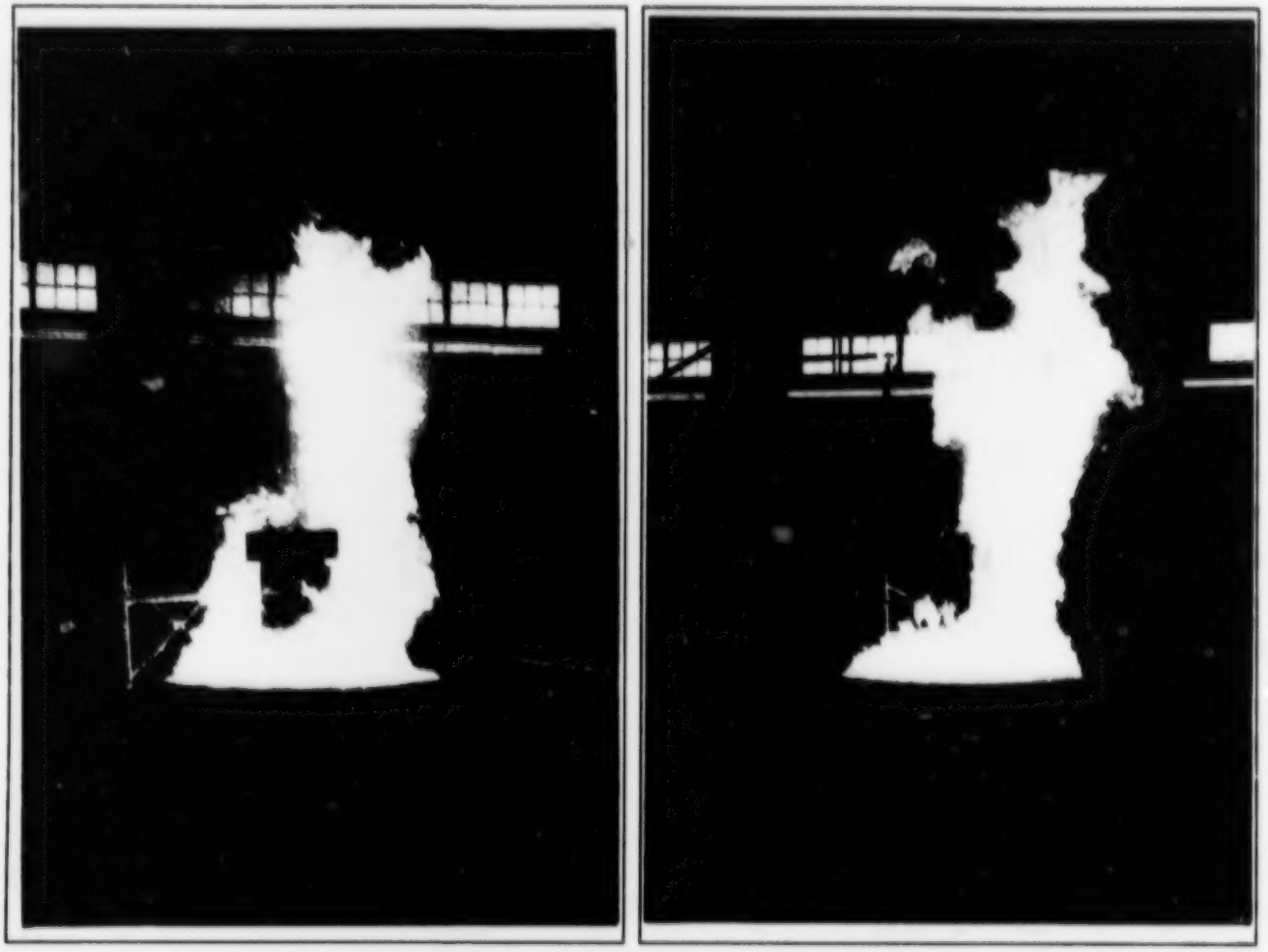


FIGURE 9

INTERMEDIATE STAGES OF FIRE DEVELOPMENT

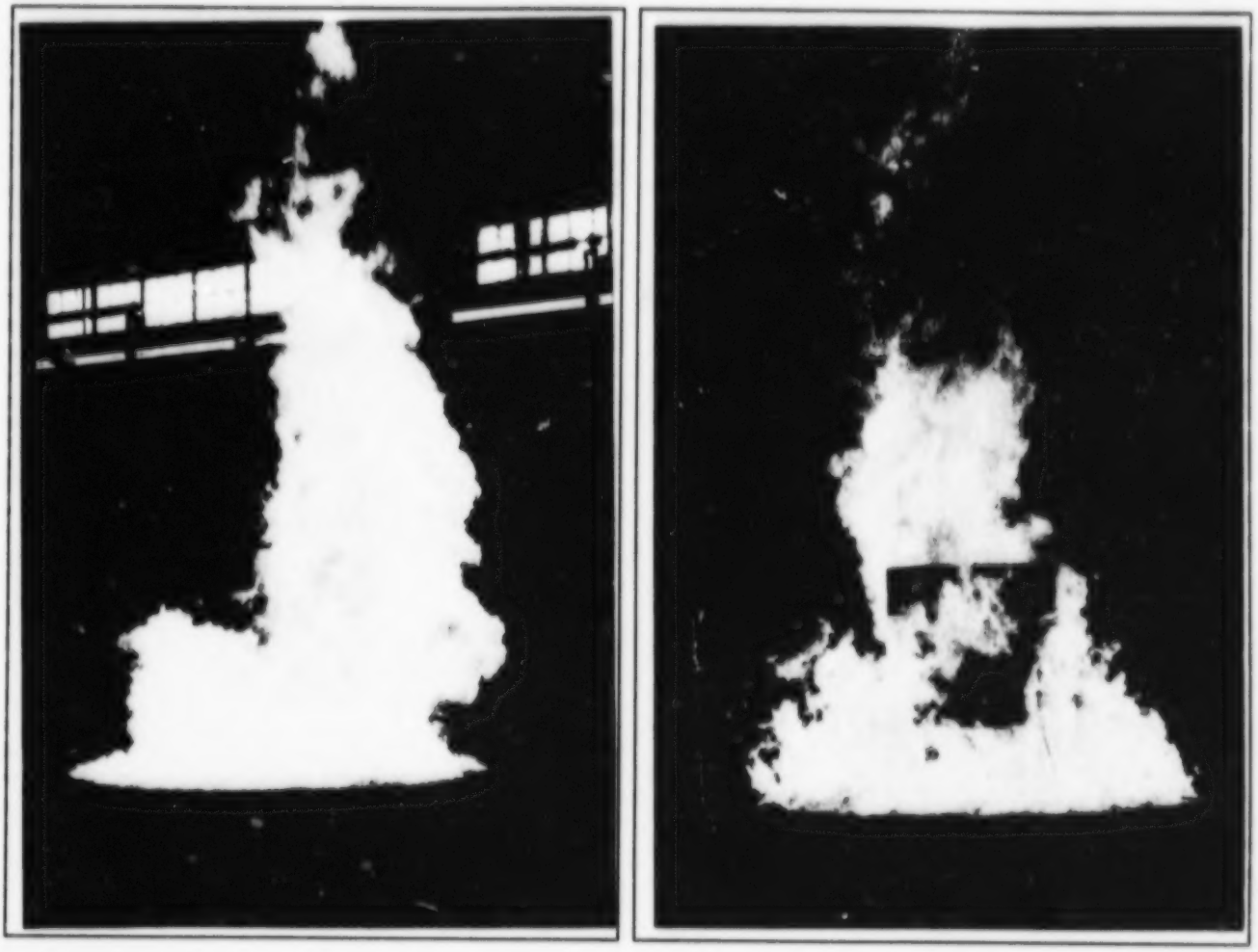


FIGURE 10

FINAL STAGES OF FIRE DEVELOPMENT

FIGURE 11

HALF-SCALE ROAD CASK AFTER FIRE TEST

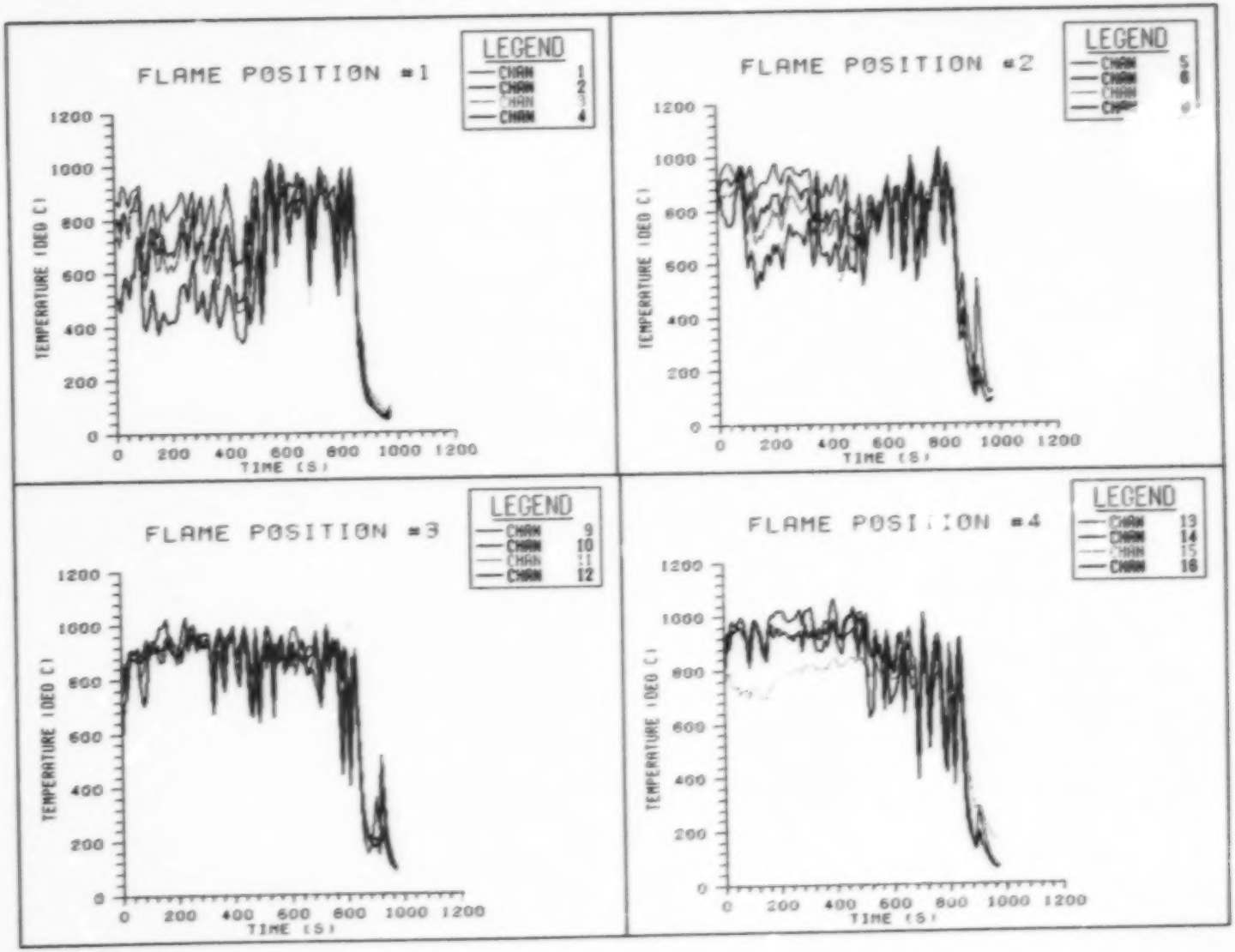


FIGURE 12

FLAME TEMPERATURES AT FOUR POSITIONS

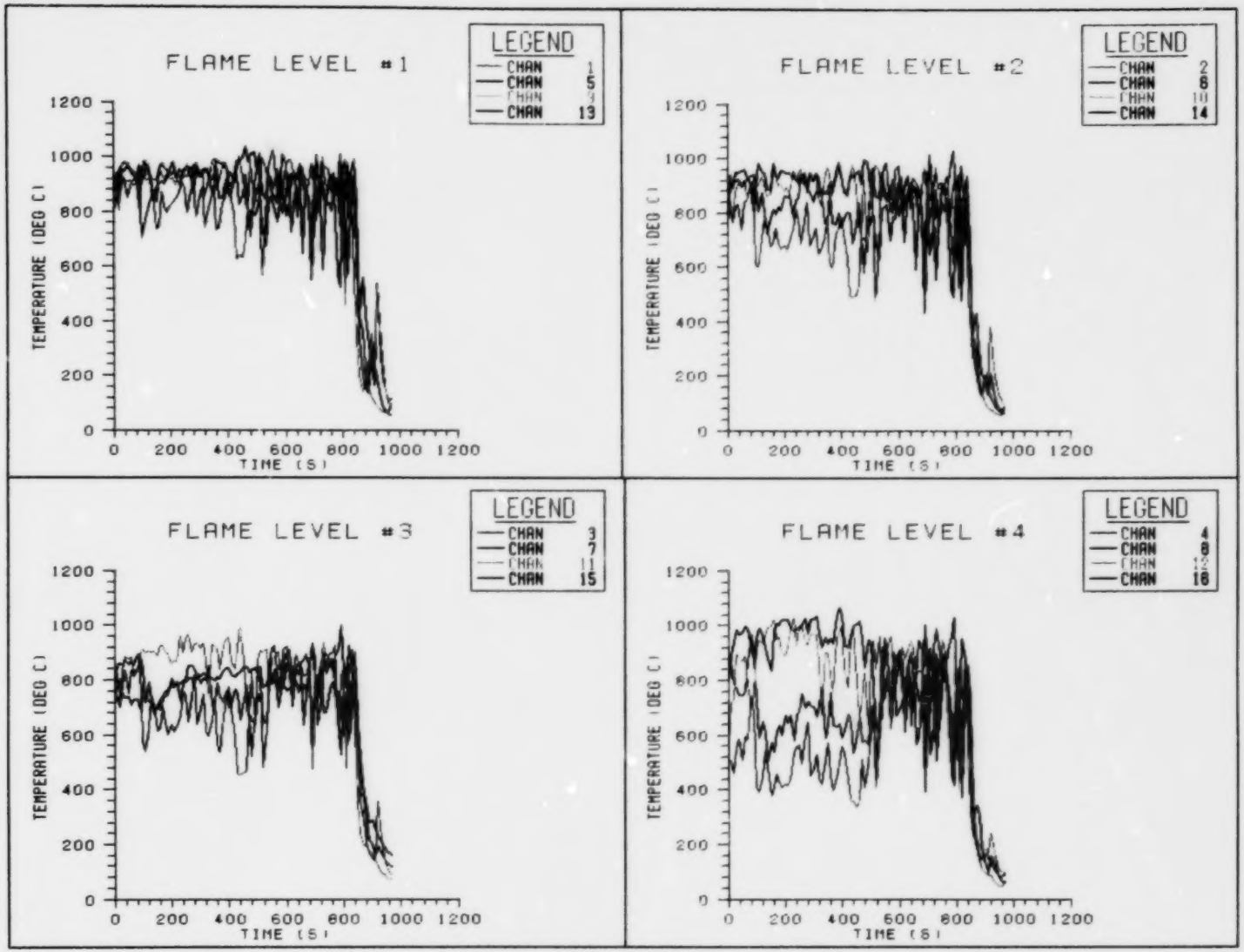


FIGURE 13

FLAME TEMPERATURES AT FOUR LEVELS

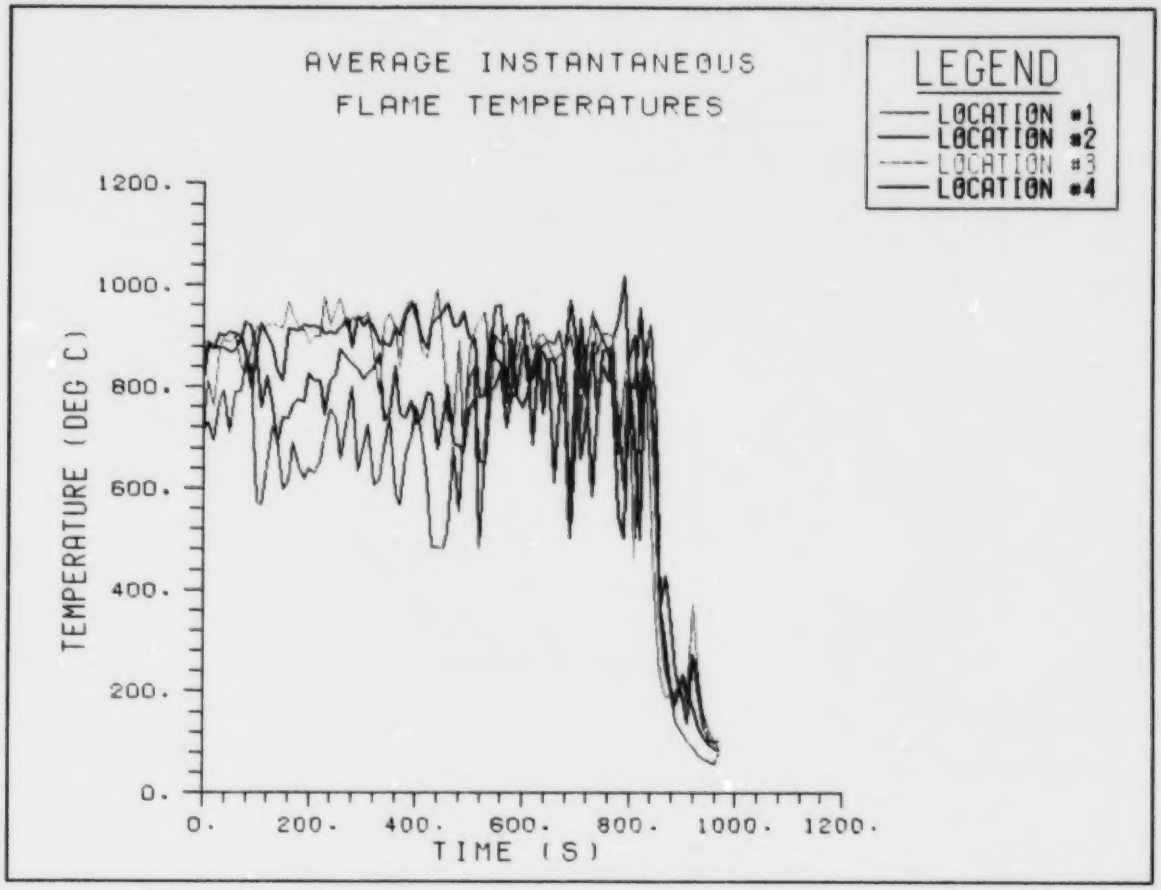


FIGURE 14

AVERAGE INSTANTANEOUS FLAME TEMPERATURES

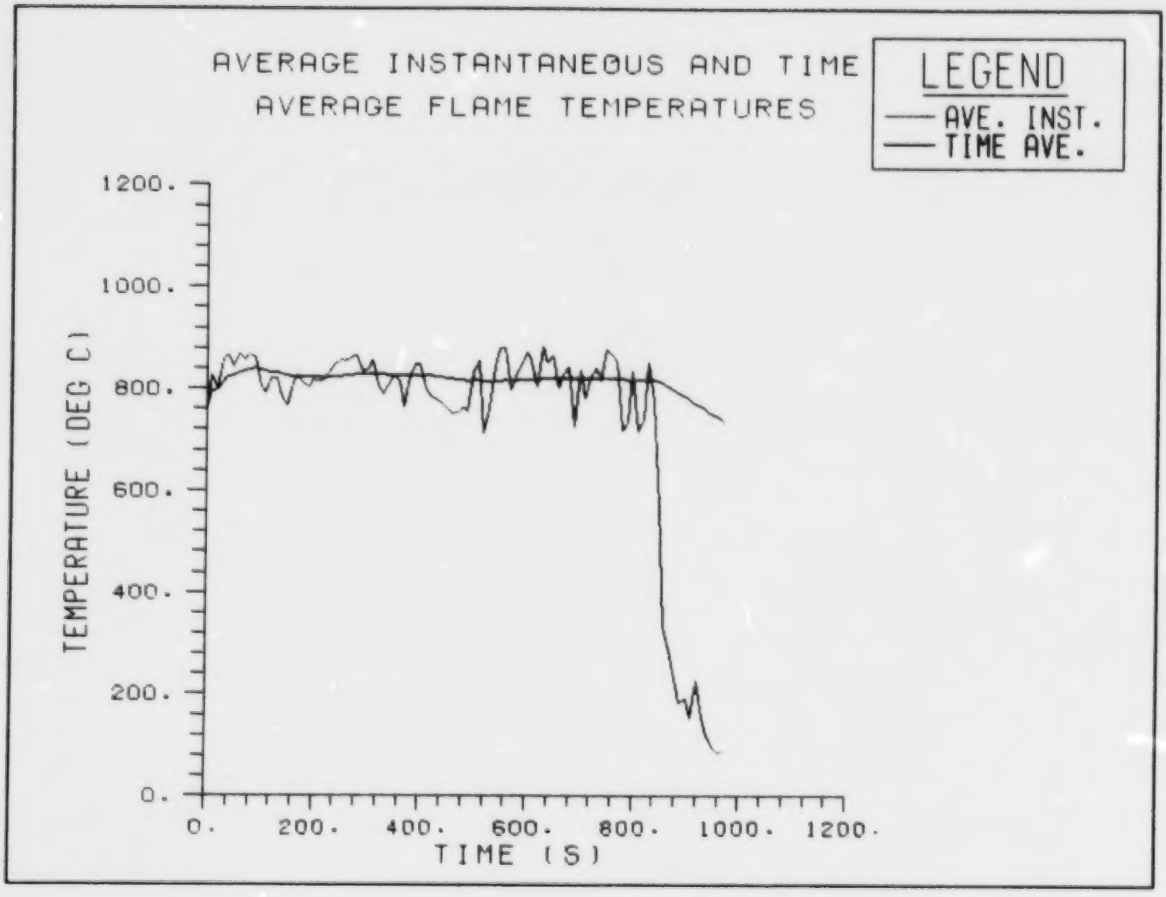


FIGURE 15

AVERAGE INSTANTANEOUS AND TIME AVERAGE FLAME TEMPERATURES BASED ON 16 FLAME TICS

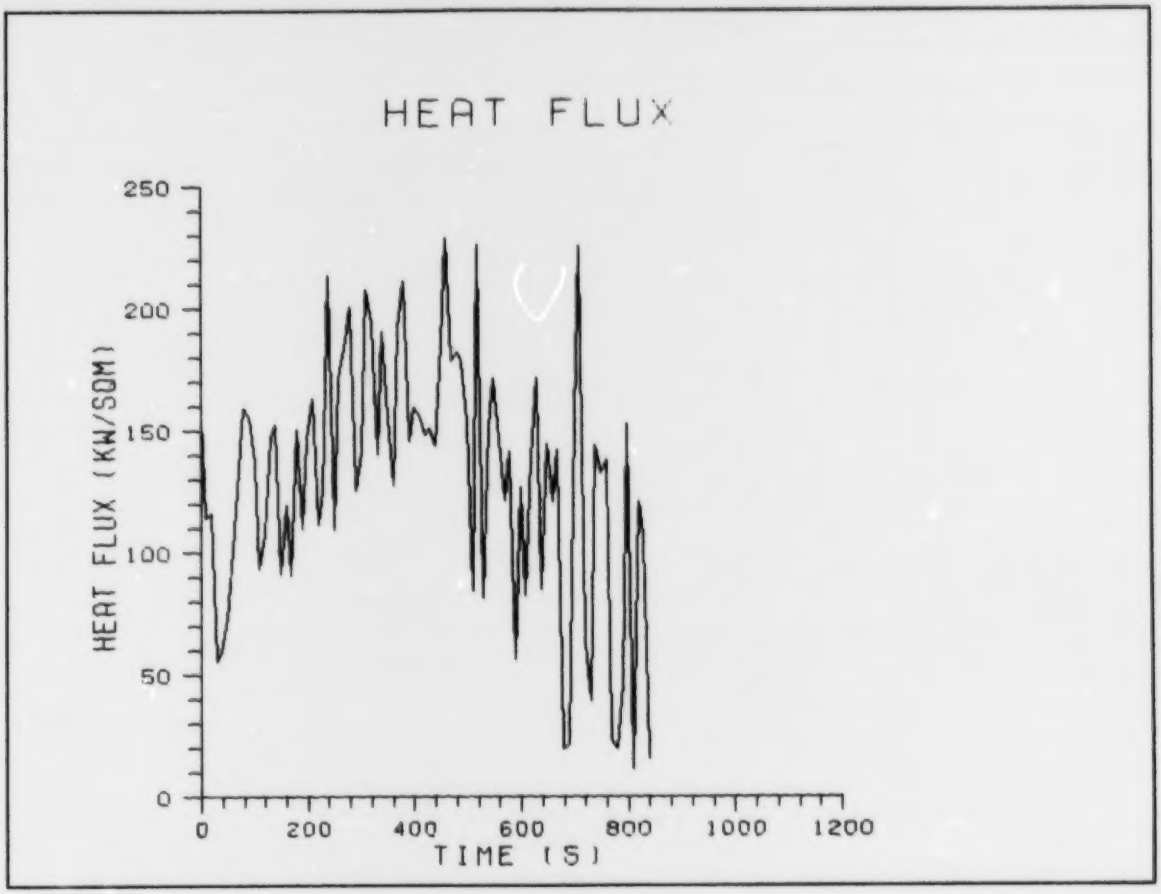


FIGURE 16

HEAT FLUX MEASUREMENTS

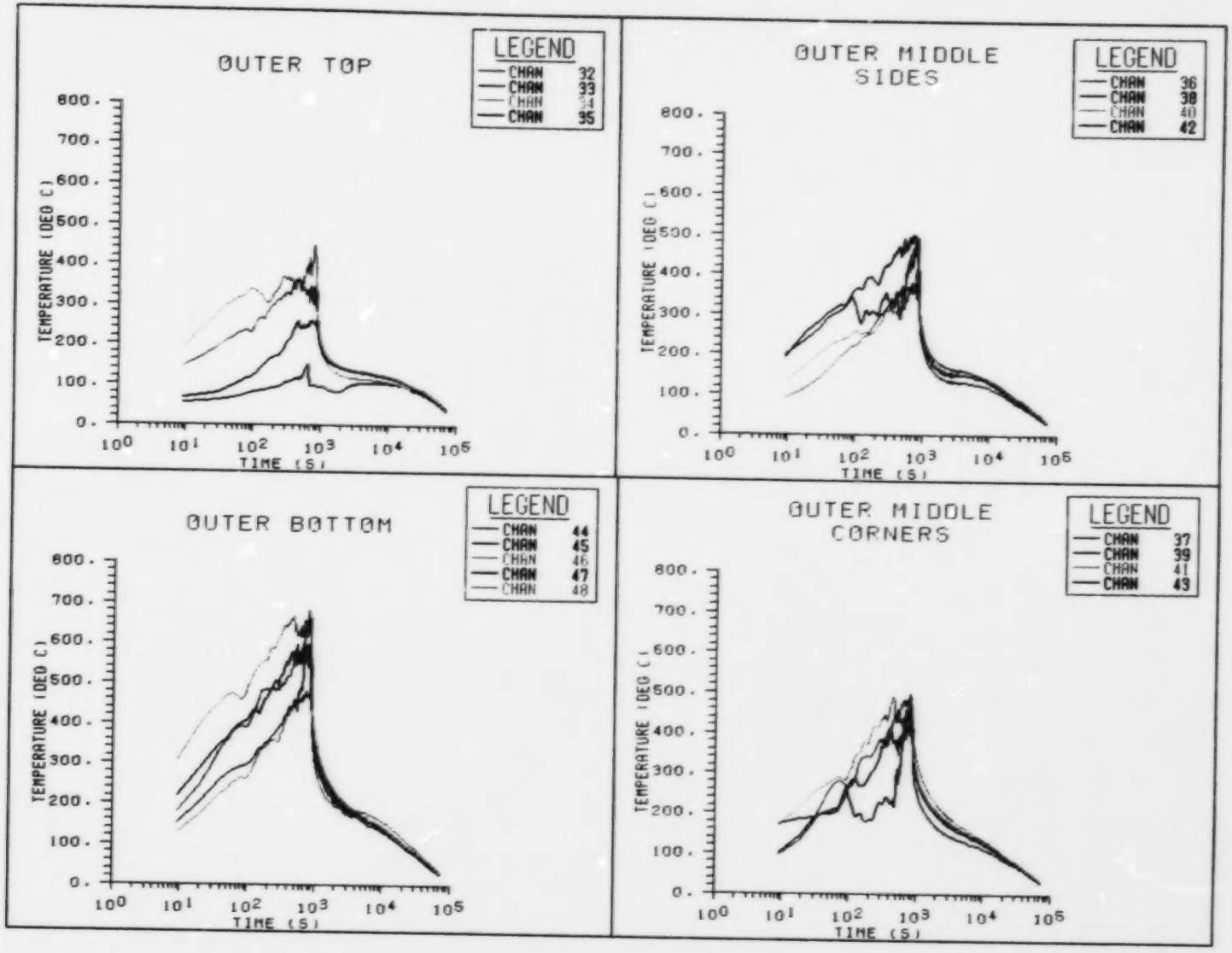


FIGURE 17

OUTER WALL TEMPERATURES

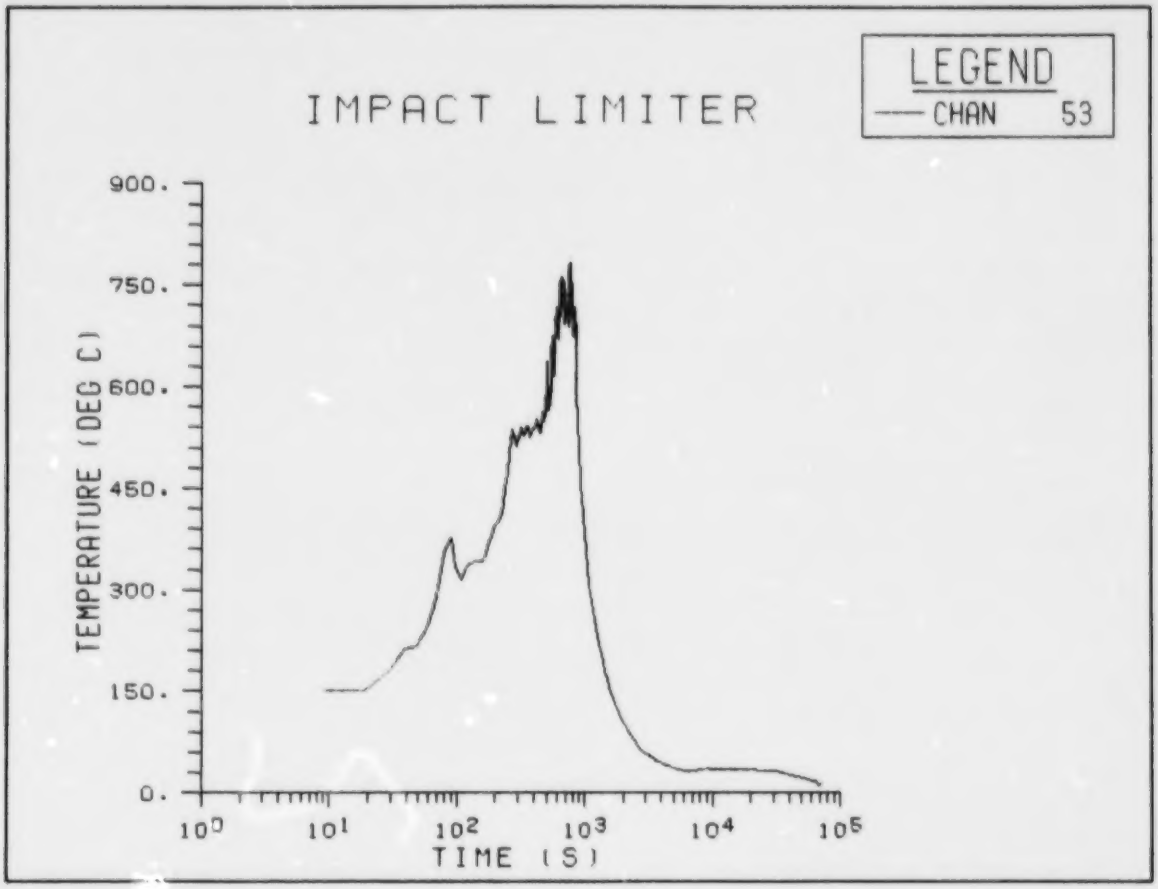


FIGURE 18

OUTER SHEATH IMPACT LIMITER TEMPERATURE

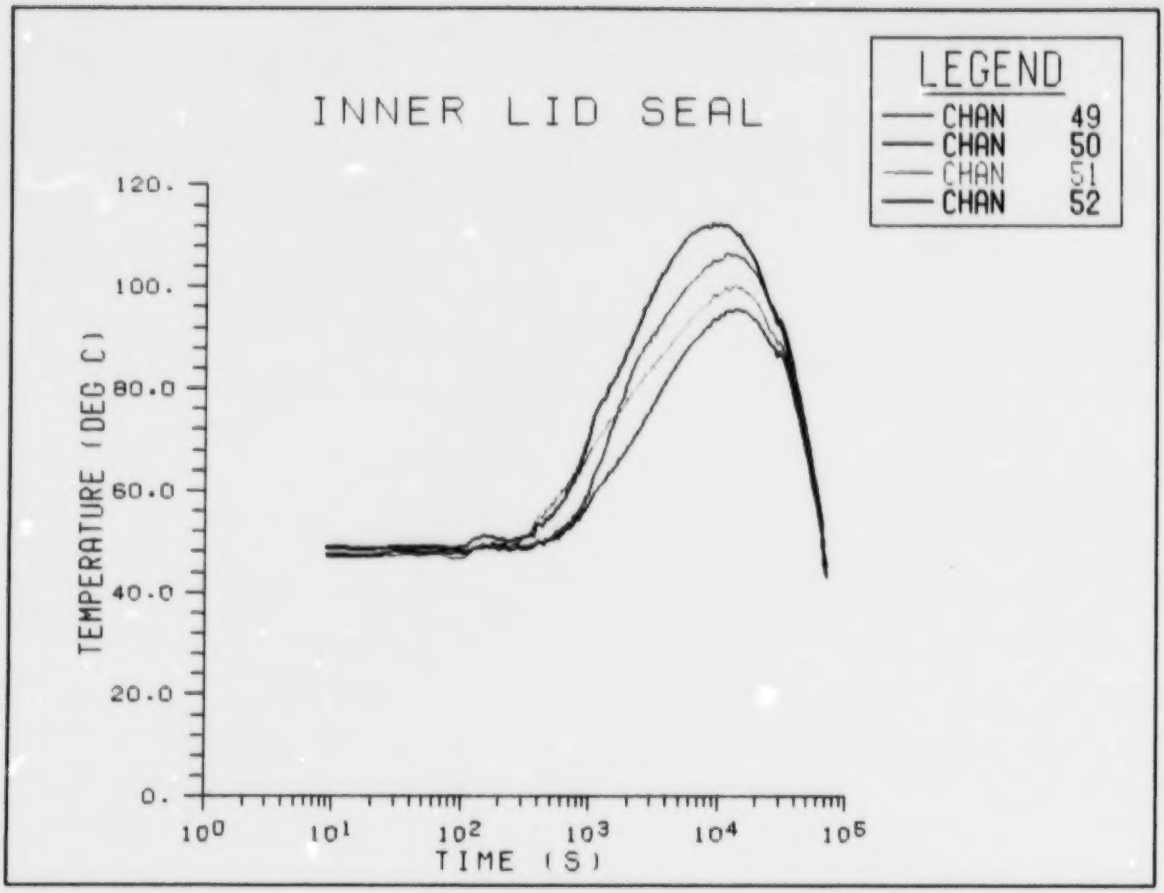
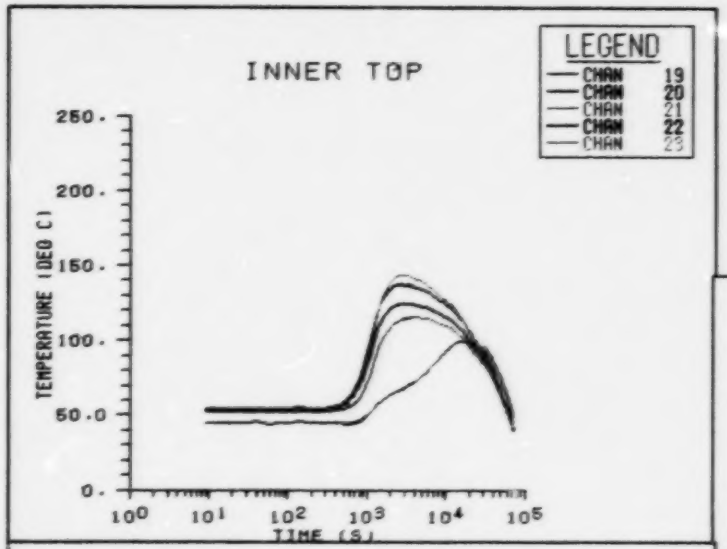
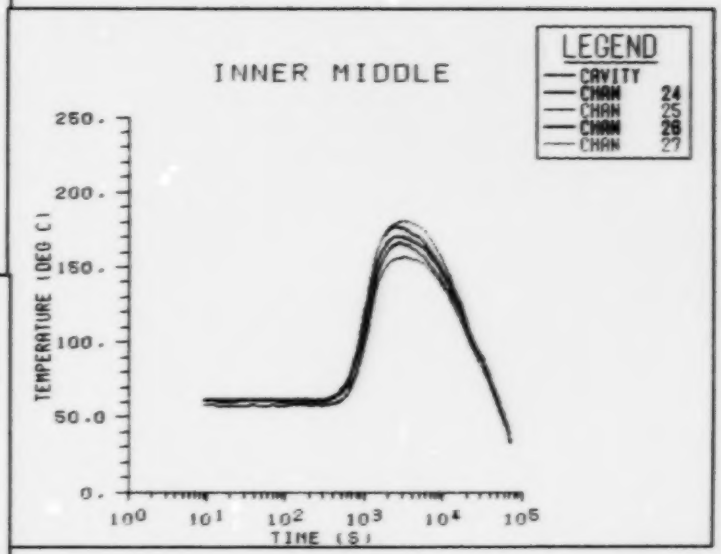


FIGURE 19

INNER LID SEAL TEMPERATURES





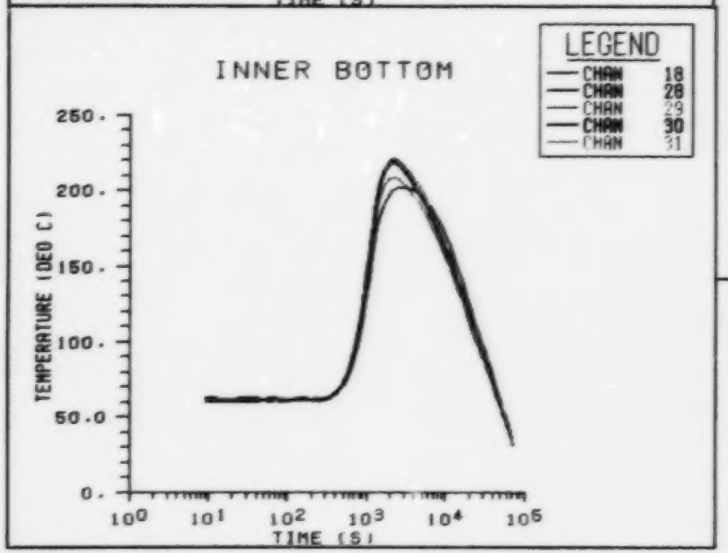


FIGURE 20

INNER WALL AND CAVITY TEMPERATURES

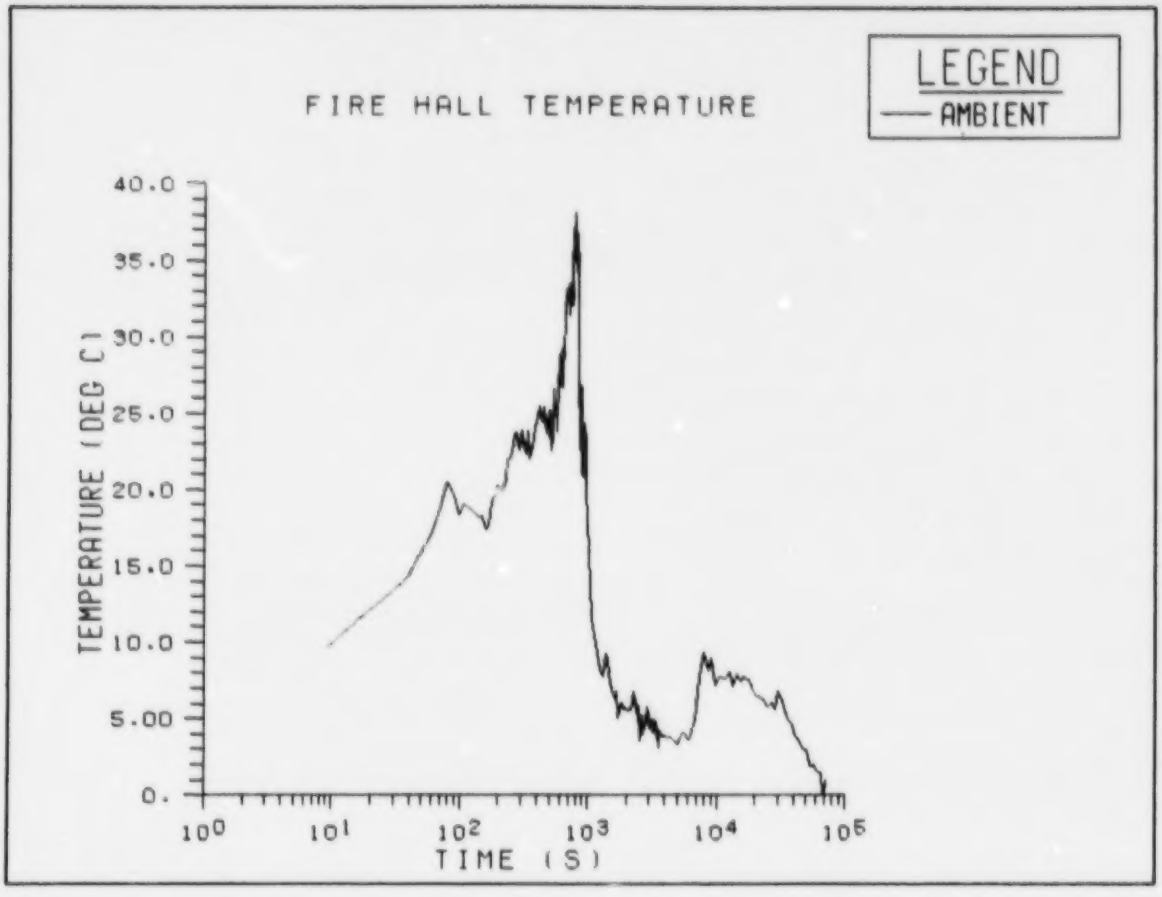


FIGURE 21

FIRE HALL TEMPERATURE

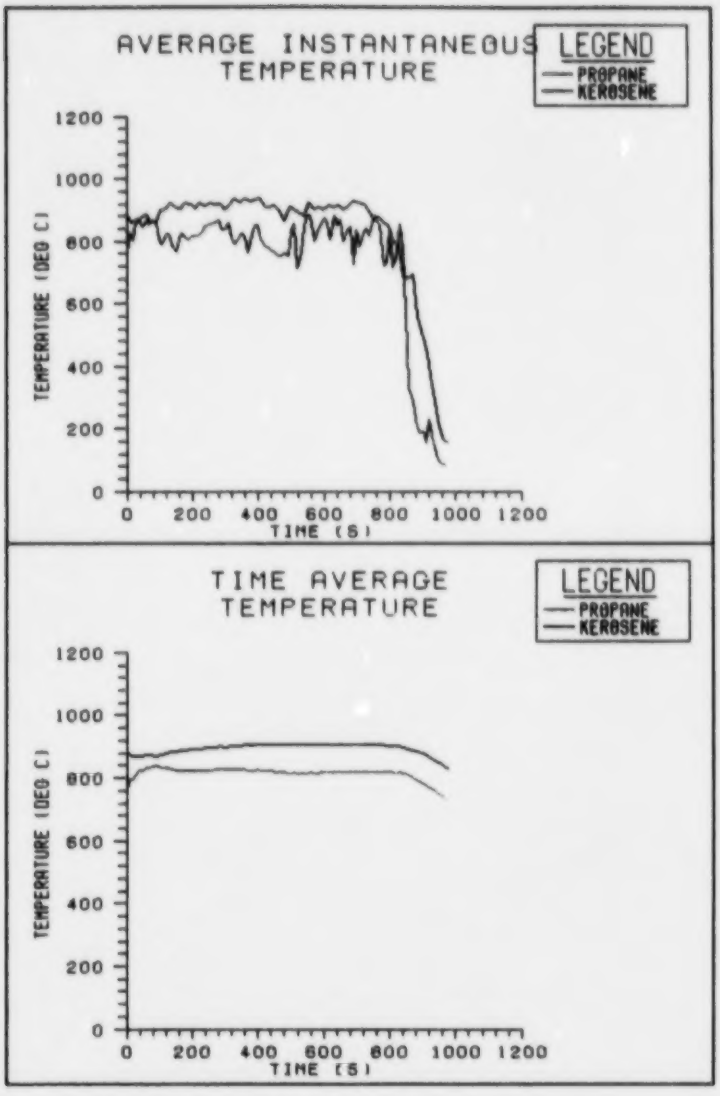


FIGURE 22

COMPARISON OF AVERAGES OF FLAME TEMPERATURES

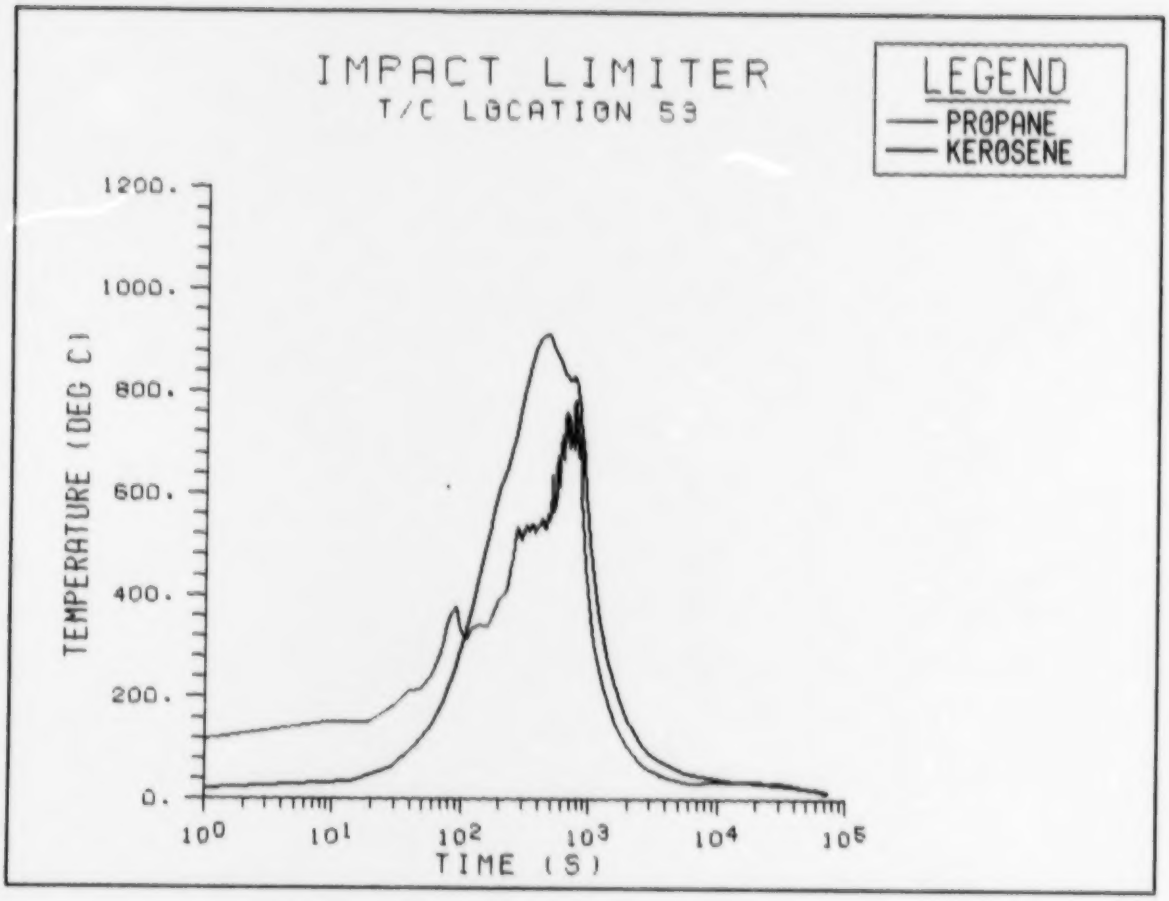


FIGURE 23

COMPARISON OF IMPACT LIMITER TEMPERATURES

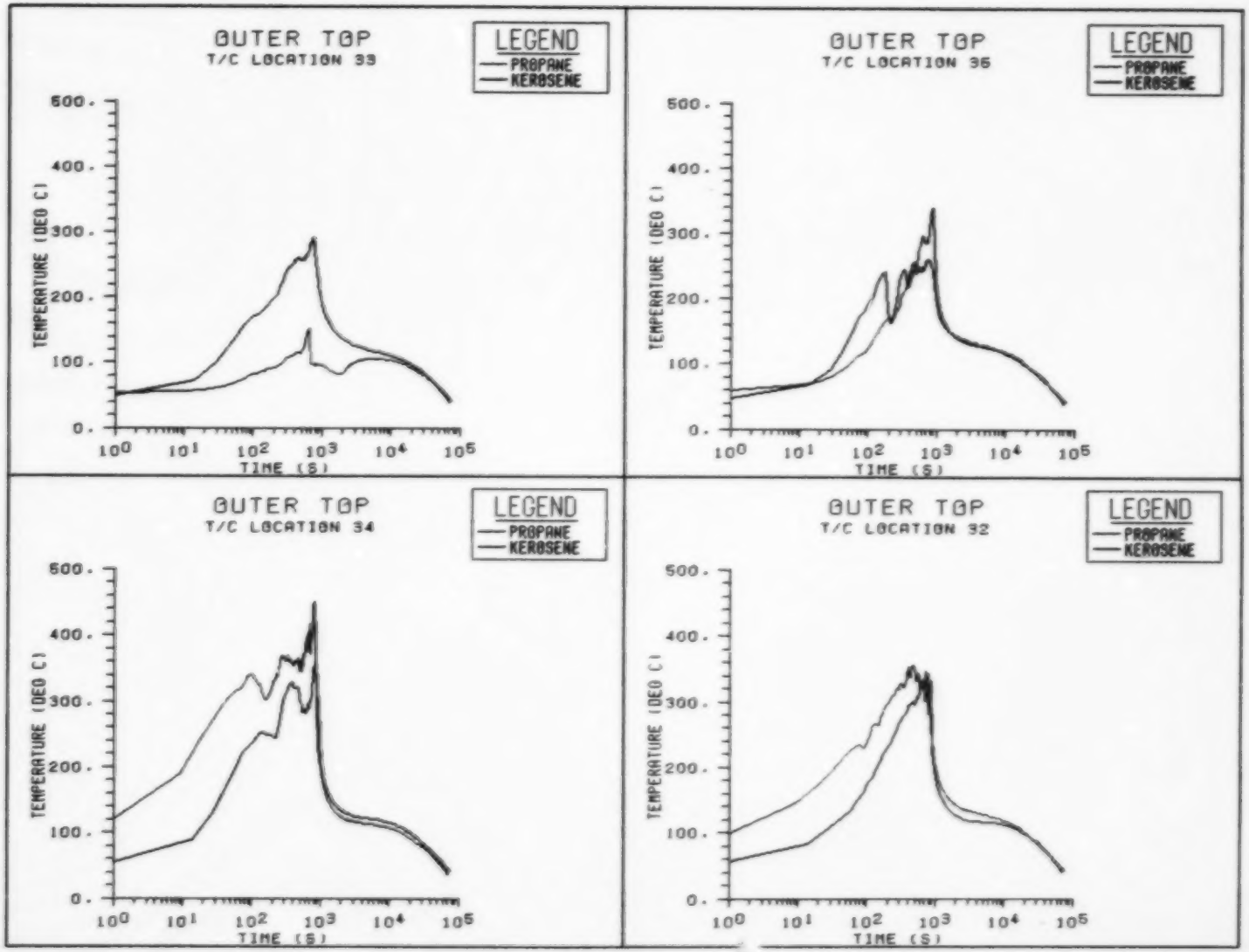


FIGURE 24

COMPARISON OF OUTER TOP SURFACE TEMPERATURES

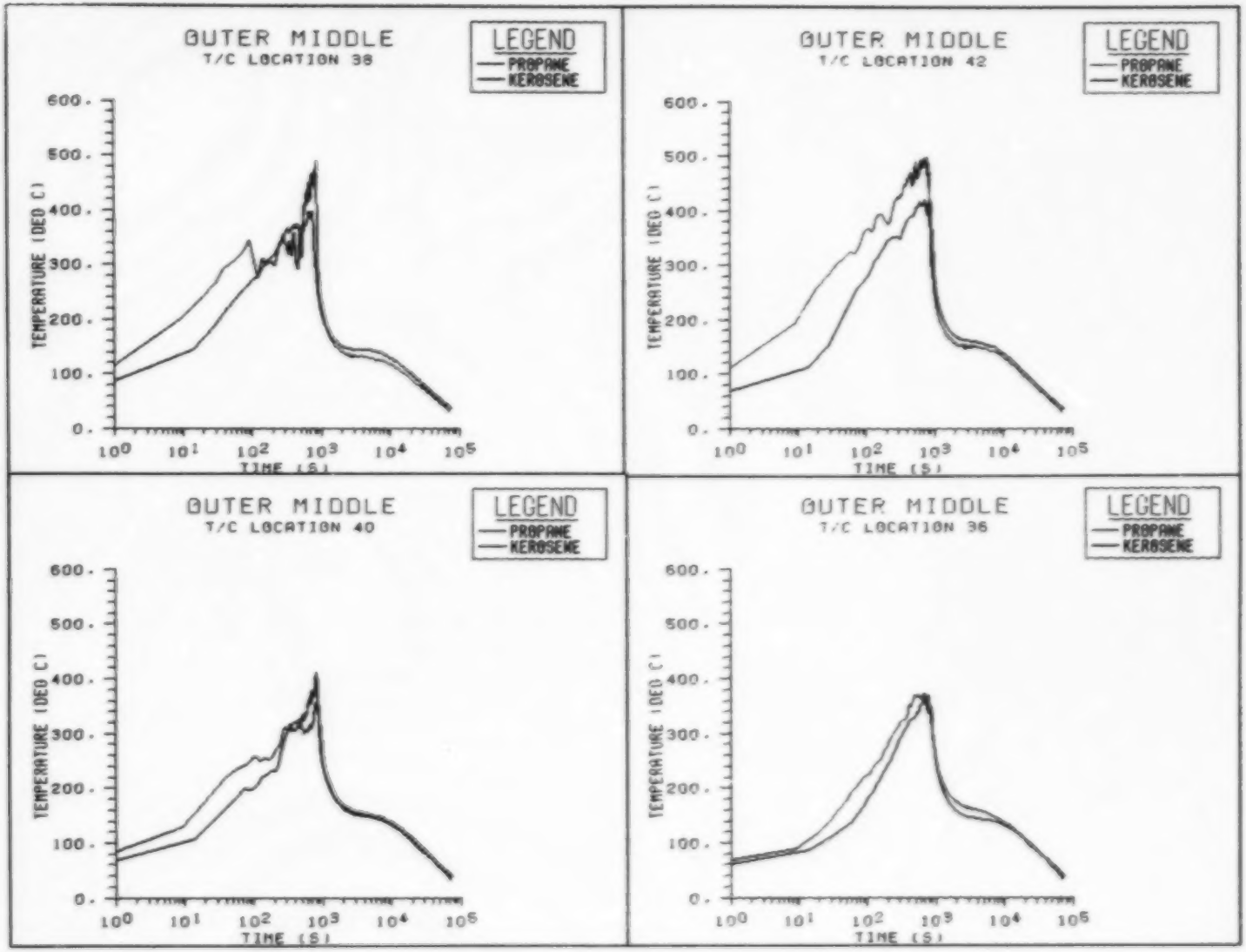


FIGURE 25

COMPARISON OF OUTER MIDDLE SURFACE TEMPERATURES (CENTRE)

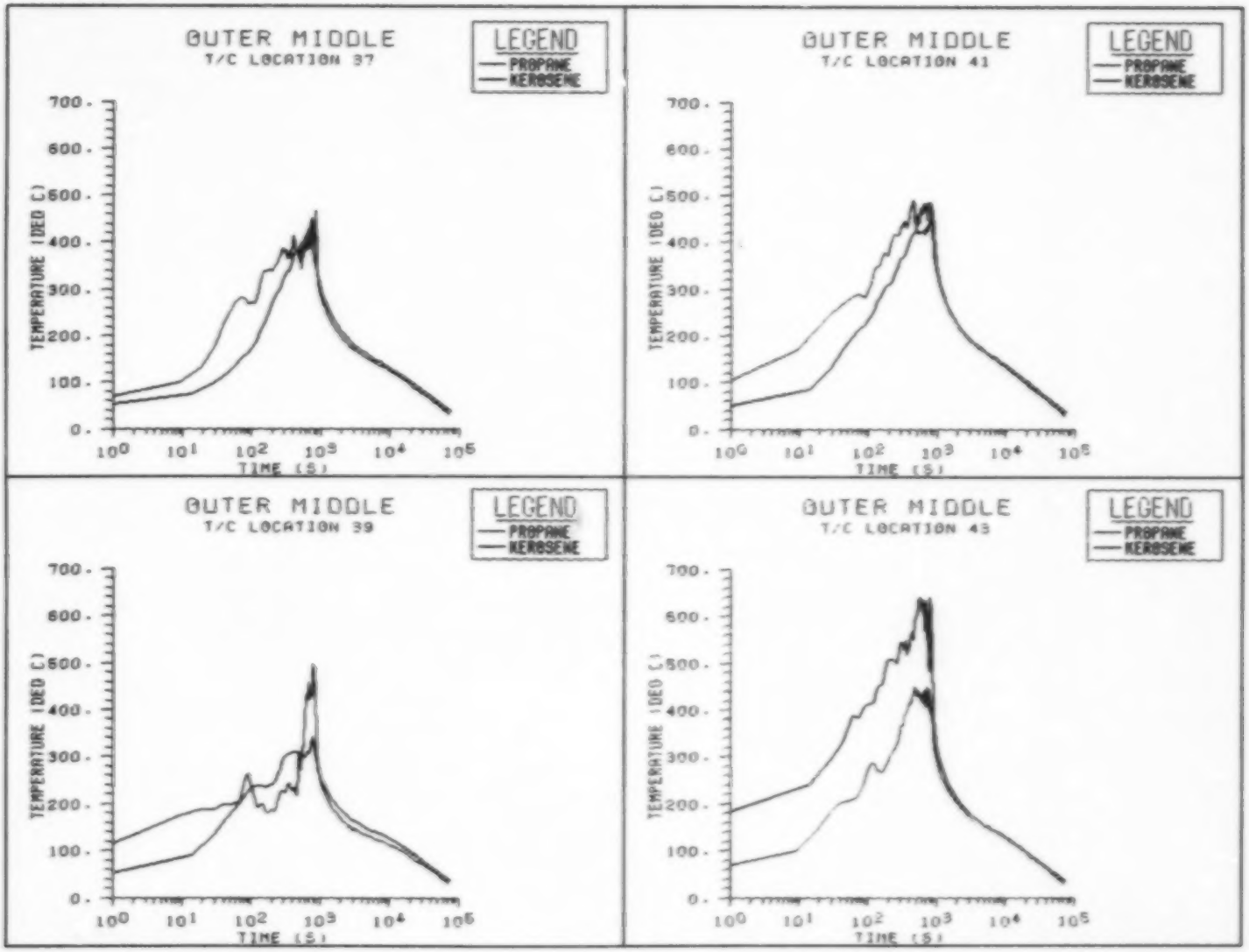


FIGURE 26

COMPARISON OF OUTER MIDDLE SURFACE TEMPERATURES (CORNERS)

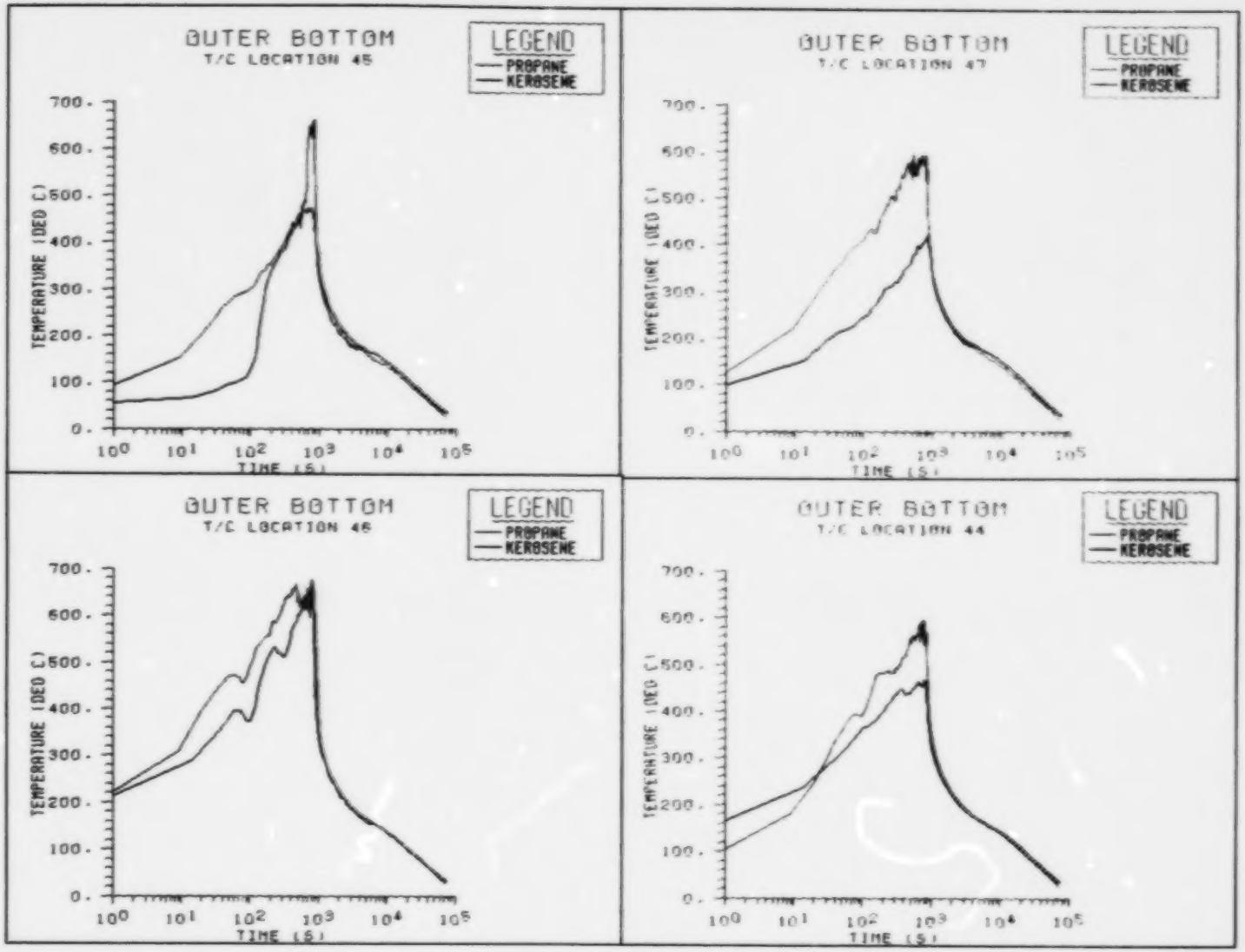


FIGURE 27

COMPARISON OF OUTER BOTTOM SURFACE TEMPERATURES

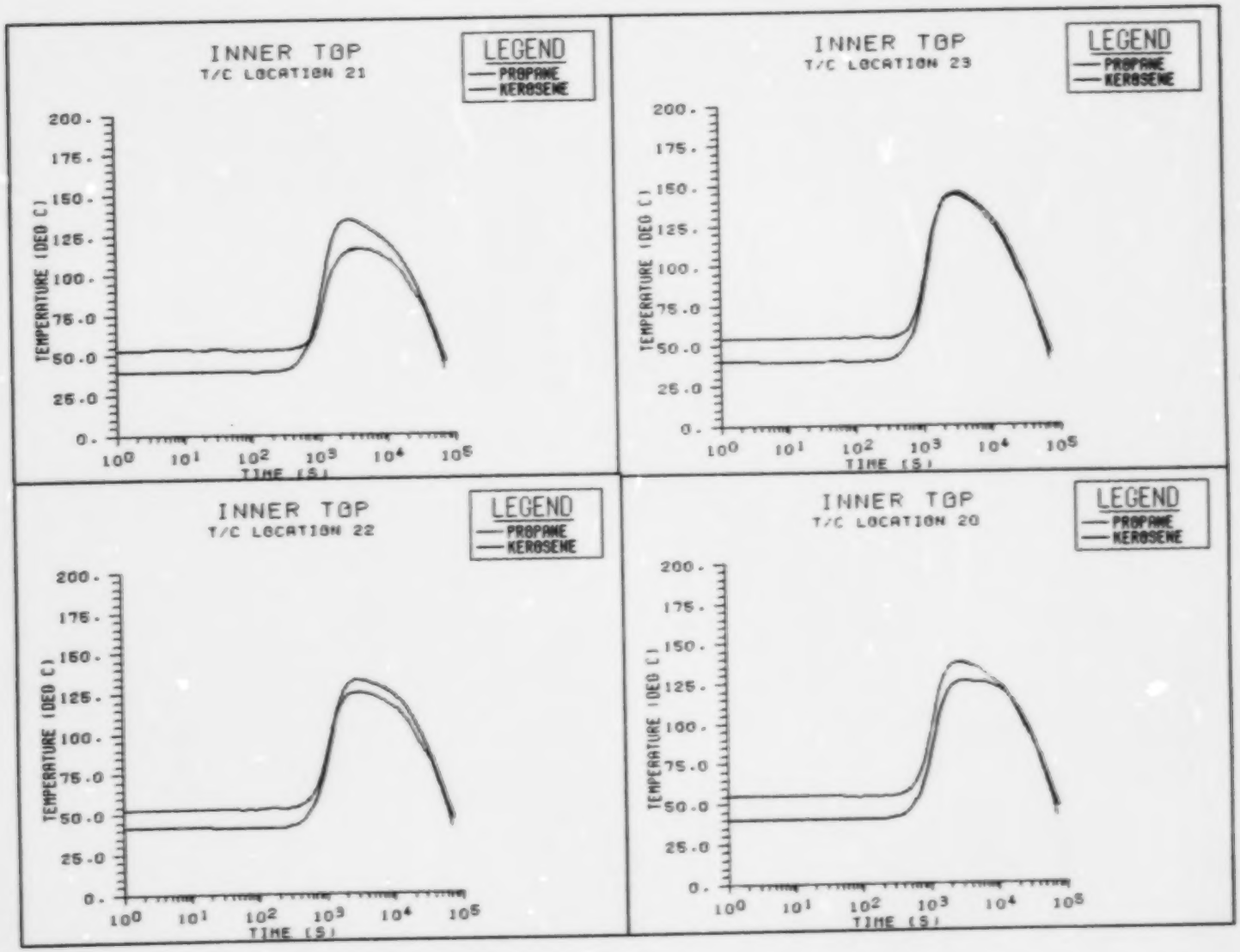


FIGURE 28

COMPARISON OF INNER TOP SURFACE TEMPERATURES

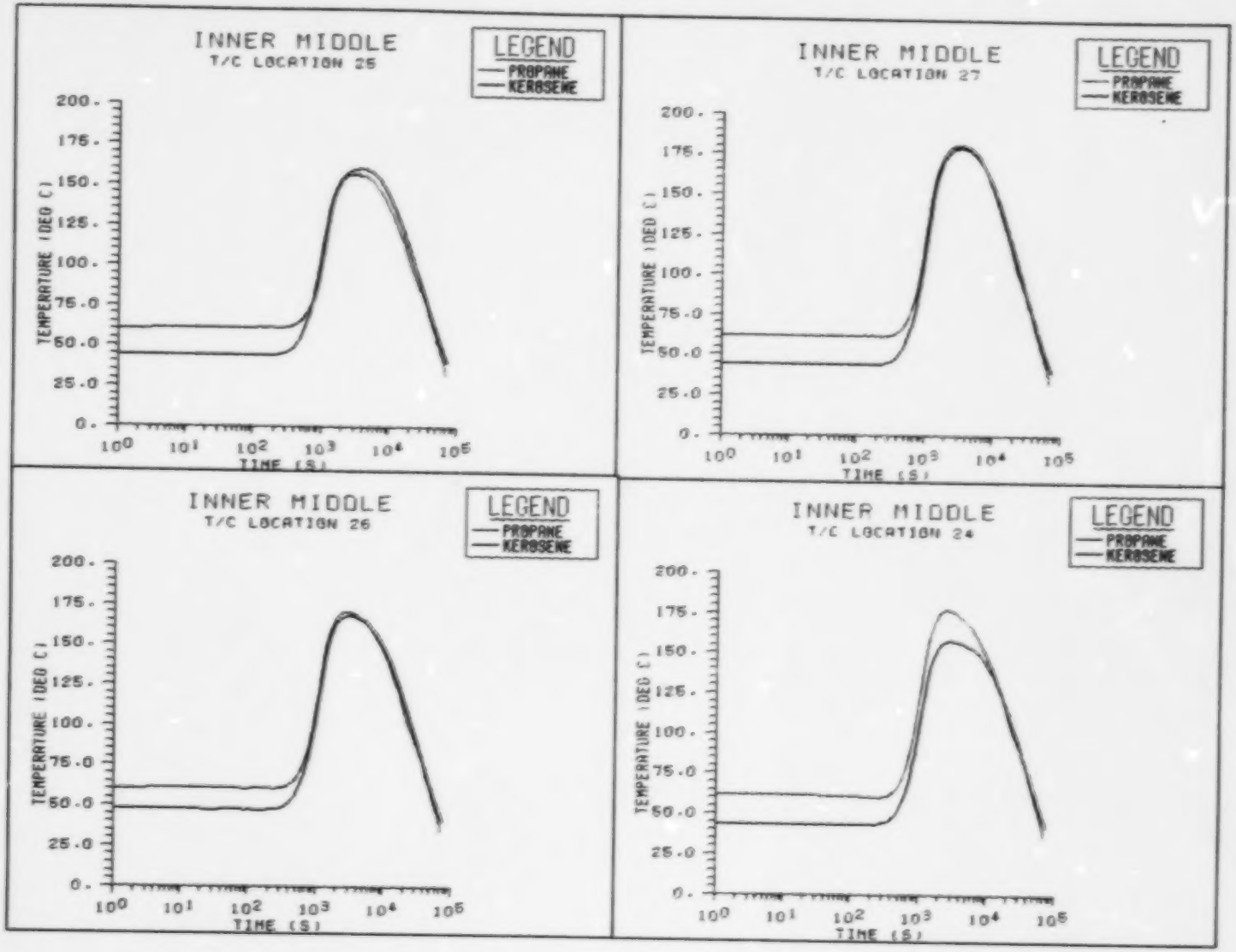


FIGURE 29

COMPARISON OF INNER MIDDLE SURFACE TEMPERATURES

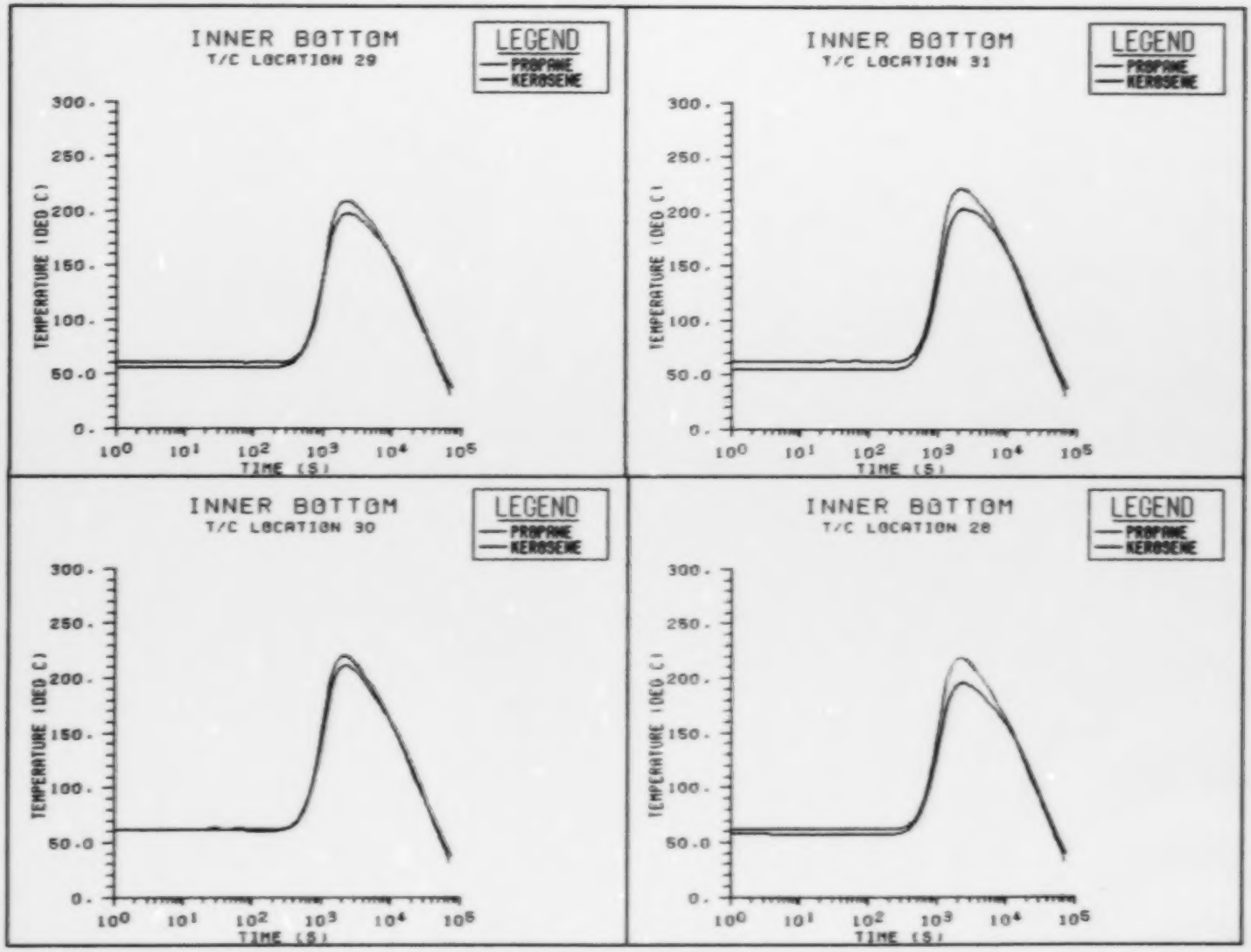


FIGURE 30

COMPARISON OF INNER BOTTOM SURFACE TEMPERATURES

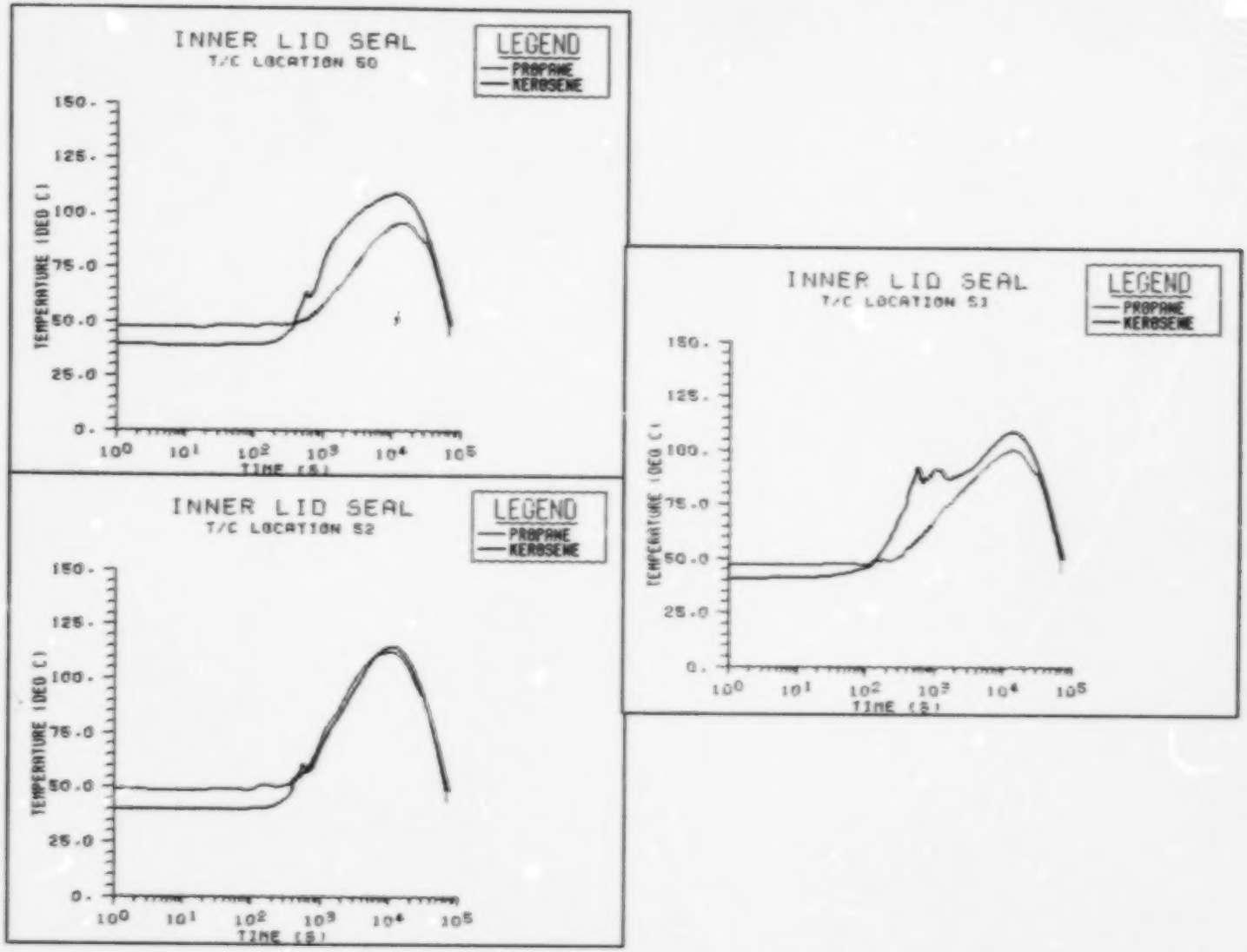


FIGURE 31

COMPARISON OF INNER LID SEAL TEMPERATURES

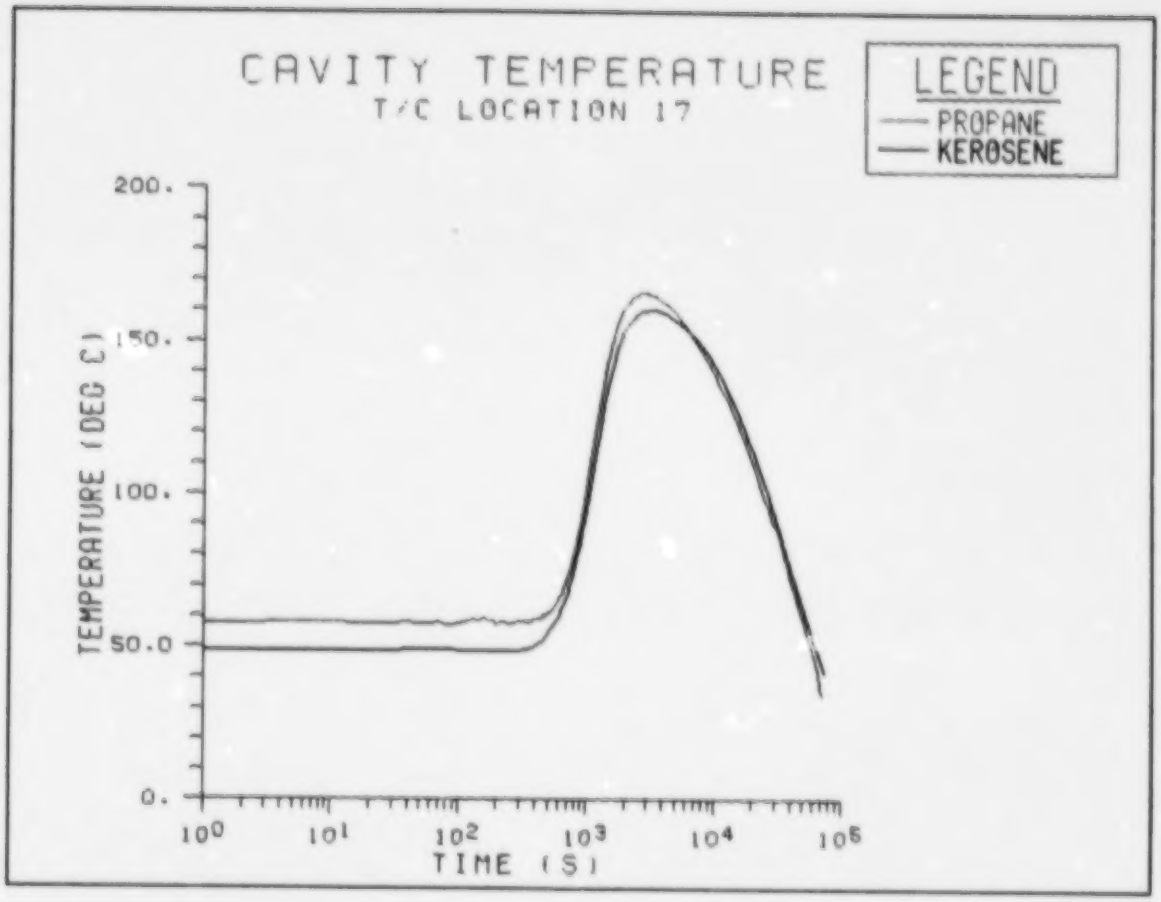


FIGURE 32

COMPARISON OF CAVITY TEMPERATURE

TABLE 1

SUMMARY OF PROPANE FIRE TEST RESULTS

Description	Temperature (°C)	* Time (S)
Average Instantaneous Flame Temperature	720 - 880	0 - 900
Time Average of Flame Temperature	800 - 820	0 - 900
Maximum Cavity Air Temperature	165	3,100
Maximum Cask Outer Surface Temperature	675	900
Maximum Impact Limiter Sheath Temperature	780	800
Maximum Outer Lid Seal Temperature	112	10,000
Maximum Cask Inner Surface Temperature	220	3,100
Maximum Fire Hall Temperature	38	900

* *Approximate Time from Start of Fire*

TABLE 2

SUMMARY OF PROPANE VS KEROSENE FIRE TEST RESULTS

Description	PROPANE		KEROSENE	
	Temperature (°C)	* Time (S)	Temperature (°C)	* Time (S)
Average Instantaneous Flame Temperature	720 - 880	0 - 900	860 - 940	0 - 700
Time Average of Flame Temperature	800 - 820	0 - 900	860 - 900	0 - 700
Maximum Cavity Air Temperature	165	3,100	160	3,500
Maximum Cask Outer Surface Temperature	675	900	645	700
Maximum Impact Limiter Sheath Temperature	780	800	960	700
Maximum Outer Lid Seal Temperature	112	10,000	114	10,000

** Approximate Time from Start of Fire*